Body schema in adolescent idiopathic scoliosis

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Declaration

This thesis is submitted to the University of Warwick in support of my application for the degree of Doctor of Philosophy. It has been composed by myself and has not been submitted in any previous application for a degree at any other institution. The work presented (including data generation and data analysis) was carried out by myself apart from the cases listed below:

- Wendy Bertram, Laura Bird, Cheryl Honeyman and Tamsin Hughes were responsible for the recruitment of the participants with AIS from their respective NHS hospital trusts and subsequent data collection.
- Sarah Bridgewater, Emma Eyre, Janet Lowe, Elizabeth Russell and Jackie Todd assisted the author with data collection from control participants.

This dissertation contains fewer than 80,000 words exclusive of appendices, bibliography, tables and equations.

Abstract

This thesis documents the studies and analyses conducted as part of a research project whose principal aim was to evaluate the role of body schema in the development of adolescent idiopathic scoliosis (AIS). There were three main research questions:

1. do adolescents with AIS differ from non-scoliotic adolescents with regard to mechanisms that are thought to underpin body schema?
2. in adolescents with AIS, is there any relationship between the mechanisms thought to underpin body schema and the magnitude of spinal deformity?
3. is there any relationship between changes in body schema and progression of the spinal deformity in AIS over time?

To answer these questions, a systematic review of neurophysiological deficits in AIS and a case-control study involving patients with AIS and non-scoliotic controls was performed along with a series of correlational and longitudinal analyses. Fifty-eight participants with AIS (cases) were recruited along with 197 age and sex-matched control participants from schools in Warwickshire, Oxfordshire, Leicestershire and Coventry. Measures of body schema as well as other self-report measures were collected at baseline for both groups. Cases were followed up at 6 and 12 months. Imaging data of spinal deformity was also collected for case participants.

The results of the systematic review and case-control analysis indicated that people with AIS did not differ significantly from non-scoliotic controls with regard to measures of body schema. The correlational and longitudinal analyses confirmed the lack of association between these two sets of parameters with no relationship between the magnitude of spinal deformity and body schema over a period of 12 months.

Secondary analyses did reveal differences between case and control participants with regard to perceived spinal deformity, pain, self-image and, to a lesser extent, function. Correlational and longitudinal analyses revealed that these differences were not related to the magnitude of spinal deformity and that perceptions of spinal deformity may be more important than the actual bony changes themselves.

List of abbreviations

AIS	adolescent idiopathic scoliosis
AUC	area under curve
BAQ	Body Awareness Questionnaire
BCa	bias corrected and accelerated (bootstrap interval)
BMI	body mass index
BSREC	Biomedical and Scientific Research Ethics Committee
C7	7th cervical vertebra
CHQ-CF-87	Child Health Questionnaire - children's form (87 items)
CI	confidence interval
CLBP	chronic low back pain
CNS	central nervous system
CoE	Church of England
CRPS	chronic regional pain syndrome
CV	cardiovascular
deg	degrees
EHI	Edinburgh Handedness Inventory
F	female
fMRI	functional magnetic resonance imaging
GOT	grating orientation task
HRQoL	health-related quality of life
ICC	intra-class correlation coefficient
IQR	inter-quartile range
ISIS-2	Integrated Shape Imaging System
ISRCTN	International Standard Randomised Controlled Trial Number
JCUH	James Cook University Hospital, Middlesbrough
JIS	juvenile idiopathic scoliosis
LBP	low back pain
LBT	line bisection test
M	male
MCID	minimal clinically important difference
MDC	minimal detectable change
MDT	movement detection threshold
MSOA	middle layer super output areas
n	number
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NIHR	National Institute of Health Research
NOC	Nuffield Orthopaedic Centre, Oxford
NRES	National Research Ethics Service
PLP	phantom limb pain
POTSI	posterior trunk symmetry index
RCT	randomised controlled trial
ROC	receiver operating characteristics
ROH	Royal Orthopaedic Hospital, Birmingham
S1	1st sacral vertebra

SAQ	Spinal Appearance Questionnaire
SAUK	Scoliosis Association, United Kingdom
SCI	spinal cord injury
SD	standard deviation
SDT	sensory discrimination testing
SE	standard error
SEAS	Scientific Exercise Approach to Scoliosis
SEM	standard error of measurement
SRS-22r	Scoliosis Research Society questionnaire - 22 items (revised)
SSE	scoliosis-specific exercise
SVV	subjective visual vertical
T1	1st thoracic vertebra
TAPS	trunk appearance perception scale
TPDT	two point discrimination threshold
TrA	Transverse abdominis
VAS	visual analogue scale
WRVAS	Walter-Reed visual assessment scale

Introduction

A definitive cause for the development of adolescent idiopathic scoliosis (AIS) has yet to be identified. The aim of this thesis is to determine whether there is any association between body schema and the development of adolescent idiopathic scoliosis as has previously been hypothesised. The objective of establishing a relationship is to facilitate novel approaches to treatment of this condition without the necessity of resorting to highly intrusive and costly interventions such as spinal fixation surgery or bracing. In doing so, it is hoped that outcomes for this patient group will be improved.

The research questions that this thesis has set out to answer are:

1. do adolescents with AIS differ from non-scoliotic adolescents with regard to mechanisms that are thought to underpin body schema?
2. in adolescents with AIS, is there any relationship between the mechanisms thought to underpin body schema and the magnitude of spinal deformity?
3. is there any relationship between changes in body schema and progression of the spinal deformity in AIS over time?

To answer these questions, four linked studies/analyses were conducted:

1. a systematic review of neurophysiological measures in people with AIS and non-scoliotic controls (research question 1).
2. a case control study involving patients with AIS and non-scoliotic controls to investigate research question 1.
3. a cross-sectional correlation analysis of baseline data from participants with AIS to assess question 2.
4. a longitudinal analysis of 6 and 12 month follow-up data from participants with AIS to evaluate question 3.

Because an observational study forms the basis of this thesis, any findings of an association between measures of body schema and AIS does not prove causality. Therefore, in order to judge whether body schema is a potential causal factor in AIS, a number of criteria will need to be met as set out by Bradford-Hill [1]. Firstly, a plausible and strong relationship will need to be established between deficits in measures of body schema and AIS (study 1 and 2: systematic

review and case control study), consistency of findings will need to be demonstrated across a range of studies linking measures of body schema and AIS (study 1: systematic review), a dose-response or biological gradient will need to be confirmed between measures of body schema and differing magnitudes of AIS (3: cross-sectional correlation analysis) and specificity and temporality in response in that changes in measures of body schema should result in changes in AIS (4: longitudinal analysis).

This thesis consists of two volumes and is structured into five broad sections.

Volume I

The first section details the background to the subsequent studies:

- Chapter 1 provides an introduction to AIS and an overview of current treatment and knowledge regarding its aetiology.
- Chapter 2 introduces the concept of body schema, its definition and role in other clinical conditions, as well as its potential role in AIS.
- Chapter 3 details a systematic review conducted to elucidate neurophysiological changes associated with AIS and provides a rationale as to why body schema is a potential factor in the development of AIS.
- Chapter 4 describes the various methods that have been used to test body schema and provides a rationale for the testing methodology subsequently employed in the studies that form part of this thesis.

Section two describes the case control study conducted as part of this thesis with the aim of answering research question 1:

- Chapter 5 describes the methodology used in the case control study conducted as part of this thesis, including participant recruitment and testing protocols.
- Chapter 6 details the results of the case control study along with a brief summary and discussion.

Section three explains the cross-sectional correlational analyses conducted to answer research question 2:

- Chapter 7 details the methodology used in the correlational analyses.
- Chapter 8 presents the results of the correlational analyses and a brief discussion of the findings.

Section 4 discusses the longitudinal analyses performed to answer research question 3:

- Chapter 9 explains the methodology used in the longitudinal analyses.
- Chapter 10 contains the results of the longitudinal analyses with a brief discussion of the findings.

Volume II

The final section draws the results of all the analyses together:

- Chapter 11 discusses the findings of the various analyses and studies conducted as part of this thesis and explores their research and clinical implications.
- Appendices detailing the recruitment paperwork (participant information sheets, consent and eligibility forms) and the measures used for this research project.

1 What is Adolescent Idiopathic Scoliosis?

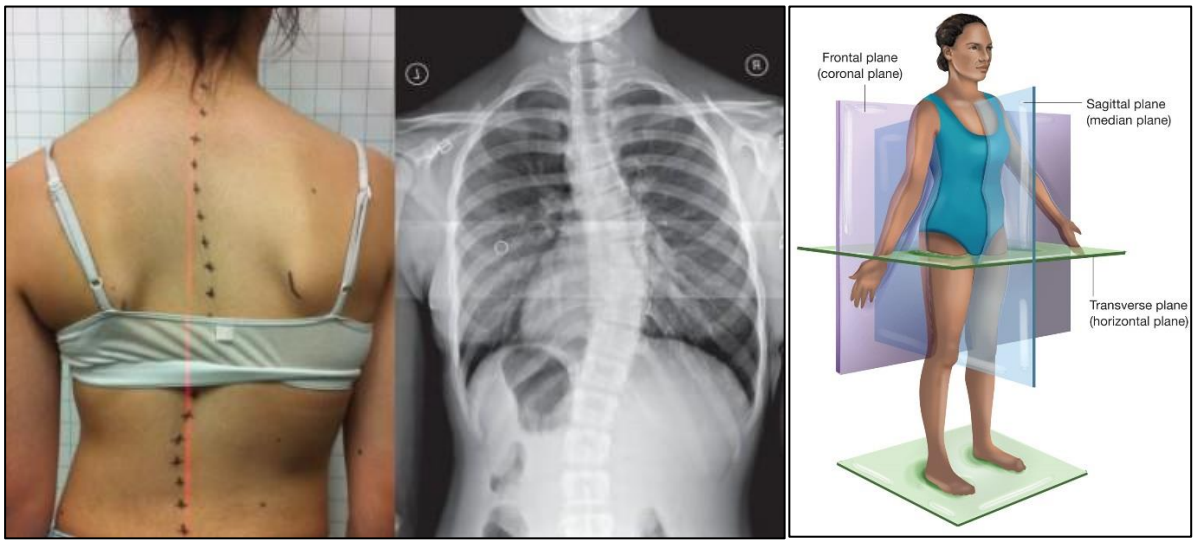
The aim of this chapter is to introduce the condition of adolescent idiopathic scoliosis, give a broad overview of what is currently known regarding its aetiology and management, and detail the issues that provide the rationale for this thesis.

1.1 Scoliosis

Scoliosis is a three dimensional deformity which involves a combination of bending and twisting of the spine [1]. It is usually characterised by the degree of lateral curvature in the frontal plane (

Figure 1.1) although the most noticeable changes in body shape (e.g. rib 'hump') are more commonly associated with changes in the sagittal and transverse planes (due to altered kyphosis/lordosis and axial rotation of the spine respectively).

Figure 1.1 Scoliotic spine and anatomical planes

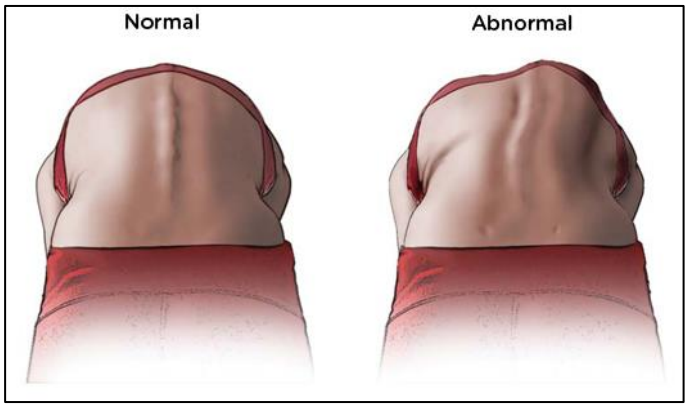


(from [2, 3])

Scoliosis is often first suspected due to asymmetries in torso shape, scapular positioning or in the level of the shoulders and/or pelvis. Clinical testing involves observation of the entire spinal region for such changes and Adam's forward bending test (Figure 1.2). Deviation off to

one side during the test or unilateral raised prominences (due to rotation of the vertebral bodies and associated ribs and/or paravertebral musculature) are indicative of a possible underlying deformity [4].

Figure 1.2 Adam's forward bending test



(from: [5])

Definitive diagnosis is provided through imaging studies with full length standing lateral and postero-anterior radiological studies typically used [6]. Despite being three-dimensional, the magnitude of the deformity is usually described by the size of the curvature in the frontal plane. A series of measurements are taken from x-ray images, either manually or via computer software, and a formula used to calculate the Cobb angle (Figure 1.3) [7]. To be classified as scoliosis, the Cobb angle must be > 10 degrees [8]. Anything less than 10 degrees is considered to be within the limits of normal variation and/or within the margin of error for calculating the Cobb angle.

Other measurement tools have been designed in an attempt to categorise the degree of deformity in all three planes and are used to varying extents. These include surface topography measures (e.g. Quantec, ISIS) which attempt to capture the changes in torso shape (Figure 1.4). Topography measures provide a contour-like map of the back surface highlighting the cosmetic changes which often are of greater concern to the patient than the size of the Cobb angle itself [9]. However, in clinical terms, the Cobb angle remains the most widely used measure.

Figure 1.3 Calculating Cobb angle

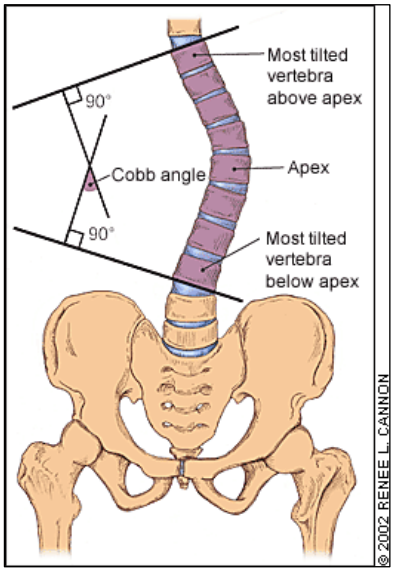
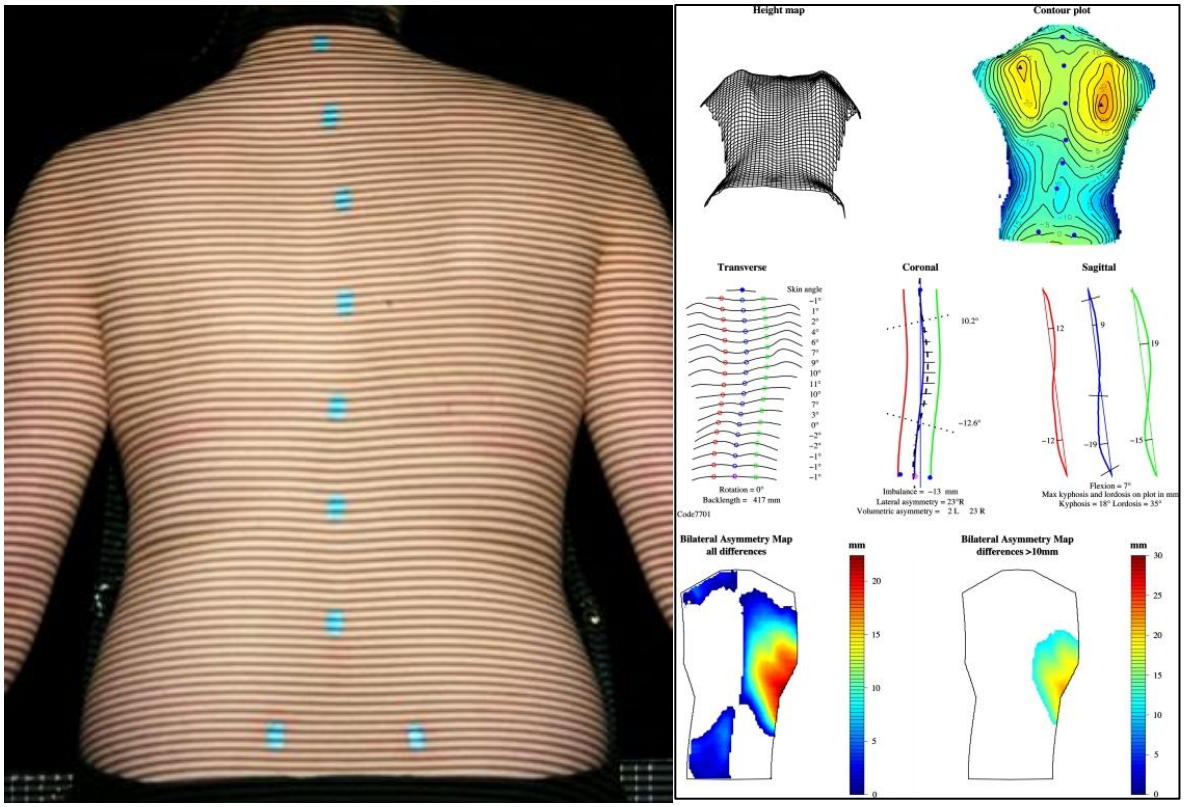


Figure 1.4 Surface topography using ISIS-2

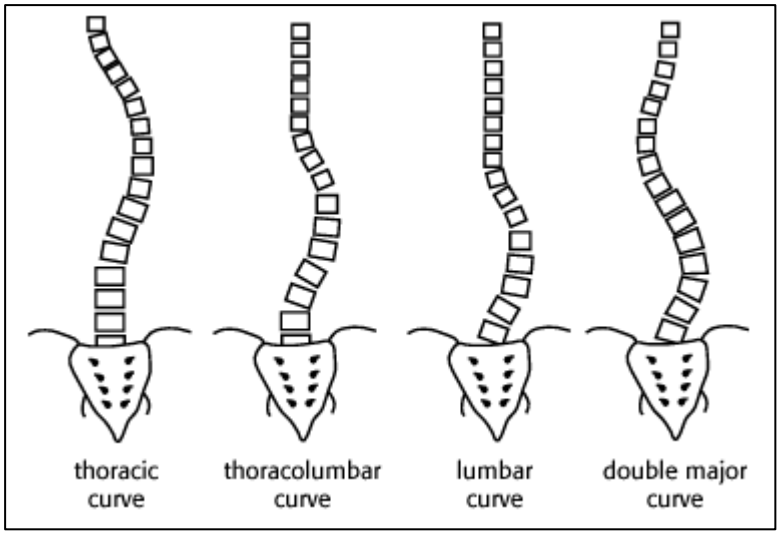


(from [10])

A number of classification systems have been devised but at its simplest, scoliosis is categorised by the number of curves (single, double or, more rarely, triple), their location (thoracic, thoracolumbar or lumbar) and the Cobb angle (Figure 1.5). The severity is generally described as mild (Cobb angle ≤ 25 degrees), moderate (25 to 45 degrees) or severe (> 45 degrees) [11].

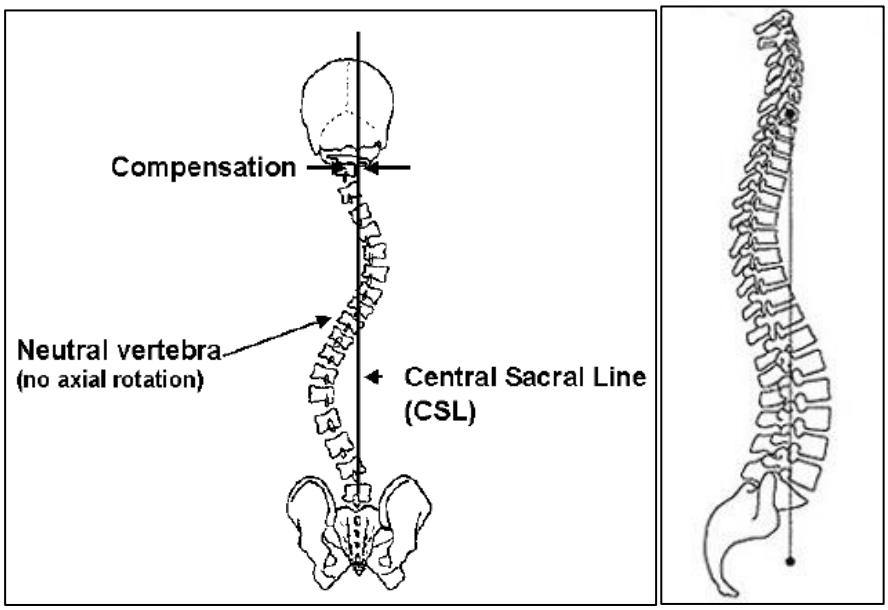
The degree of balance (i.e. the extent to which upper spine/neck is in line with the sacrum) in both frontal and sagittal planes is another factor commonly used in classification (Figure 1.6). Coronal balance measures are obtained by drawing vertical plumb lines down from the spinous process of C7 and upwards from the centre of S1 on x-rays. The distance between these two lines indicates the magnitude of coronal imbalance with 0 mm signifying they are perfectly in line and therefore 'in balance'. Sagittal balance is obtained by a similar process using plumb lines drawn down from the centre of T1 and upwards from the posterior-superior aspect of the S1 vertebral body.

Figure 1.5 Type of curves



(from [12])

Figure 1.6 Spinal balance frontal and sagittal



(from [13])

1.2 Types of scoliosis

Scoliosis is not a disease in itself, rather it is a description of a common end result of multiple causal pathways (Figure 1.7). These include congenital, specific neuromuscular or syndromic conditions (e.g. cerebral palsy, muscular dystrophy, Marfan's syndrome), trauma or degeneration of the spine resulting in structural changes [14].

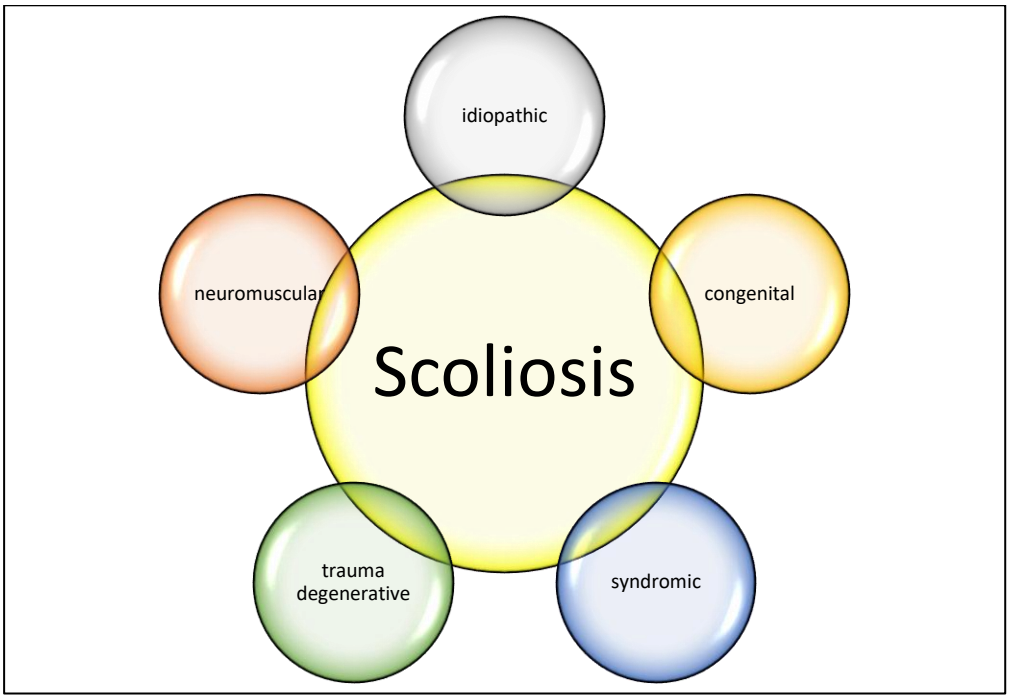
The most common forms of scoliosis appear to develop during childhood growth spurts for reasons which, at this stage, are not fully understood. These are termed idiopathic scoliosis and are categorised according to when they develop: juvenile idiopathic scoliosis (JIS or early-onset IS) or adolescent idiopathic scoliosis (AIS or late-onset IS). Around 70-80% of all cases of scoliosis are idiopathic in nature, with AIS the most common form [14, 15].

1.3 Adolescent idiopathic scoliosis

As the name suggests, AIS develops around the time of the adolescent growth spurt although it may not always be diagnosed until much later depending on the size and nature of the resulting spinal changes, and opportunities for observing the spine in young adolescents. Screening programmes are relatively rare which limits the possibility of observing the spine in

this age group, especially amongst young females as they pass through a particularly sensitive phase of physical and psychological development.

Figure 1.7 Types of scoliosis



1.3.1 Prevalence

Reported prevalence figures for AIS range from 0.5 to 4.3% (Table 1.1) although larger curves are less common [16].

The disparity in estimates is likely to be a reflection of the different populations, age groups, diagnostic criteria and data collection methods used. For children aged 10-16 years, prevalence rates of 2-3% are often reported [31], implying that there are 100,000 - 150,000 people with AIS in the UK [32]. Females suffer to a greater extent than males, with overall ratios of between 2 to 4:1 reported in the literature. With larger curves (>30 degrees), the difference becomes more extreme with ratios of between 7 to 10 females for every male [16, 31].

Table 1.1 Reported prevalence rates for AIS

Authors	Year	country	age group	Prevalence* (%)
Stirling et al [17]	**1996**	**England**	**6-14yrs**	**0.5**
Wong et al [18]	**2005**	**Singapore**	**6-14yrs**	**0.6**
Ueno et al [19]	**2011**	**Japan**	**11-14yrs**	**0.9**
Span et al [20]	**1976**	**Israel**	**10-16yrs**	**1.5**
Soucacos et al [21]	**1997**	**Greece**	**9-14yrs**	**1.7**
Morais et al [22]	**1985**	**Canada**	**8-15yrs**	**1.8**
O'Brien & Van Akkerveeken [23]	**1977**	**England**	**11-14yrs**	**2.0**
Robitaille et al [24]	**1984**	**Canada**	**children**	**2.1**
do Espirito Santo et al [25]	**2011**	**Brazil**	**children**	**2.2**
Dickson et al [26]	**1980**	**England**	**13-14yrs**	**2.5**
Smyrnis et al [27]	**1979**	**Greece**	**11-12yrs**	**2.7**
Dickson [28]	**1983**	**England**	**children**	**2.8**
Suh et al [29]	**2011**	**Korea**	**10-14yrs**	**3.3**
de Souza et al [30]	**2013**	**Brazil**	**10-14yrs**	**4.3**

* Cobb angle >10 degrees

1.3.2 Effects of AIS

The most common and potentially noticeable effect of AIS is the physical change to the shape of the torso. This does not always directly correlate with the size of the curve as defined by the Cobb angle. While the Cobb angle captures the degree of lateral curvature, often it is the degree of axial rotation along with kyphotic/lordotic changes of the spine that lead to greater visible effects [10]. These cosmetic changes are usually of greatest concern to the patient, and can lead to emotional and psychological issues related to body image, self-esteem and overall quality of life at a particularly vulnerable time [14].

Despite the general clinical consensus that pain is not a major feature, the literature is less definitive with numerous reports suggesting that pain along with the cosmetic changes are the principal features of AIS [33]. However, it is difficult to determine whether the pain that is reported in AIS is a direct result of the condition itself or whether it merely reflects the normal prevalence figures for back pain in the wider adolescent population [6, 8].

Alterations in normal function and cardiovascular (CV) capacity are not normally associated with AIS [6]. It is only when the degree of spinal deformity reaches extreme levels, often associated with other forms of scoliosis but rarely seen in AIS, that function and CV capacity may be compromised. Accordingly, patients are typically advised to continue with normal activities and not to limit physical activity [15, 34].

The last major effect of AIS is the potential for the curve to progress in adulthood. This is a major consideration with regard to possible treatment options. Once skeletal maturity has been reached, the potential for the deformity to further increase is limited but still possible and may require ongoing treatment. This depends on the magnitude and nature of the scoliotic changes once the growth phase has ended. Curves with Cobb angles greater than 30 degrees are particularly susceptible to further progress in adulthood [11].

1.3.3 Management of AIS

Current treatment options for AIS are very limited and, in severe cases, extremely invasive in nature. The primary aim is to prevent curve progression past a point where further complications may ensue, including further progression in adulthood.

Treatment generally consists of:

- monitoring ('watchful waiting')
- bracing and/or exercise
- surgery

The regular monitoring of patients, even those who do not undergo more intensive measures, involves frequent x-rays. Six or 12 monthly check-ups are a common scenario with subsequent exposure to large doses of radiation at a particularly vulnerable growth stage [10]. Although steps have been taken to limit the amount of radiation exposure as much as possible, including the use of other forms of imaging, x-rays remain a fundamental component of monitoring condition progression and decision-making.

Part of the reason for frequent monitoring is the difficulty in determining which cases will go on to develop deformities that require more intensive intervention. Predictive factors include the size of Cobb angle and maturity (usually determined by age, Risser sign and, in females, menarchal status) at initial presentation, along with sex and curve type. Greater Cobb angle,

lower age and skeletal maturity at initial diagnosis, thoracic curves and being female (especially pre-menarchal) predispose to greater levels of progression [6]. However, these are indicators only and do not necessarily predict progression in all cases. More importantly, they do not suggest which type of treatment will be of greater benefit.

Scoliosis-specific exercise (SSE) regimes are routinely prescribed (either alone or in conjunction with bracing) in Europe but only rarely used in the UK. Various methods/schools exist (e.g. Schroth, SEAS) but there is little definitive evidence of effectiveness. A Cochrane review in 2012 found only one RCT and concluded that *"There is a lack of high-quality evidence to recommend the use of SSE for AIS. "* The authors went on to recommend that *"…better quality research needs to be conducted before the use of SSE can be recommended in clinical practice*" [11]. A more recent systematic review of SSE for AIS included a number of studies conducted since the Cochrane review. The authors concluded that exercise is effective at reducing spinal deformity (as defined by the Cobb angle) and improving functional outcome, although the overall level of evidence was of low quality [35].

Ten percent of those diagnosed with AIS go on to develop deformities of sufficient magnitude to require more intensive measures [34], generally involving a bracing regime and/or spinal fusion surgery.

Bracing is an intrusive and uncomfortable intervention which can require the brace to be worn for 23 hours per day for up to four years [36, 37]. Understandably, adherence to bracing regimes is often poor. There is also some uncertainty as to its effectiveness. Papers included in a recent Cochrane review consistently showed that bracing was able to prevent curve progression but, due to methodological shortcomings in the included studies, the evidence was of low to very low quality [38].

Surgery is a very extensive procedure involving exposure of large segments of the spine and substantial fixation which, whilst reducing curve progression, also permanently limits mobility in the affected part of the vertebral column and torso [39]. Spinal fusion also comes with a risk of complications estimated to occur in approximately 6% of patients. These include pulmonary complications, wound infection, neurological damage [40], or even death [41]. Both the physical and emotional impact on the child and the economic cost to the NHS is high with

surgical costs alone reaching up to £20,000, plus a post-op inpatient stay of 5-7 days and subsequent follow-up [42].

1.3.4 Causes of AIS

As implied by the name, the cause of AIS is unknown although it is likely that it is multi-factorial [43]. It is defined by the age of onset and the absence of any identifiable cause rather than the presence of any particular factor. It has also been suggested that there may be two different sets of mechanisms at work: those that are involved in the initial development of the curve, and those related to subsequent progression [44-46].

The majority of factors that have been implicated in AIS can be grouped under the following headings:

1) genetic
2) musculoskeletal
3) metabolic
4) hormonal
5) neurological

These have been explored to a greater or lesser extent in the literature although no definitive cause has as yet been identified. Many of the differences found in AIS during investigation of these factors appear to be secondary rather than causal.

1.3.4.1 Genetic

Although there appears to be some genetic component, with increased incidence amongst relatives (particularly twins), the specific nature of the link has yet to be established. More progress has been made in deleting potential suspect genes than in identifying specific pathways of inheritance [47]. The general conclusions of most reviews on this subject agree that AIS *"… may be most consistent with a multifactorial inheritance model involving several to many genes, interplaying with unknown environmental factors…..while families with dominant inheritance may exist, [A]IS is generally a 'complex' genetic disease that is not easily explained by existing inheritance models*" [48].

1.3.4.2 Other factors

Despite the enormous amount of investigation into other factors involved in the pathogenesis of AIS, few concrete conclusions have been reached. The wide-ranging hunt for possible causes has led one reviewer to comment that "*In attempting to develop a logistical model for causality on the basis of information in the literature, one is impressed by the volume of data that do not appear to be interrelated*" [49].

In an attempt to clarify existing research, Schlosser et al [50] conducted a systematic review of studies comparing untreated AIS patients with healthy adolescents on abnormalities other than genetics and the deformity of the spine itself. Of the initial 88 eligible studies, only 21 were included in their final synthesis. Of the other 67 studies, 47 involved a high risk-of-bias and 20 did not report quantitative data in enough detail. The included studies examined 14 factors thought to be involved in the pathogenesis of AIS, categorised under the broad headings of neuromuscular, metabolic and anthropometric factors (Figure 1.8).

Figure 1.8 Abnormalities included in Schlosser et al review

	Associated with AIS	Non-associated with AIS
Strong evidence		
Moderate evidence	**Neuromuscular** • Impaired gait control **Metabolic:** • Decreased bone mineral density	
Weak evidence	**Neuromuscular** • Different vestibular morphometry • Decreased cerebral cortical thickness • Different volumes cerebellar regions • Asymmetry of somatosensory evoked potentials • Decreased trunk muscle strength **Anthropometric** • Increased corrected body height • Decreased body weight • Increased breast asymmetry **Metabolic** • Impaired bone quality	**Neuromuscular** • End-level of the spinal cord (conus medullaris) **Anthropometric** • Body height **Metabolic** • Serum leptin levels

Insufficient evidence
Neuromuscular • Cerebellar tonsil position • Regional brain volumes • Spinal cord/vertebra length ratio • Muscle spindle function • Shoulder muscle strength • Corpus calosum volume • Electromyographic activity back muscles **Metabolic:** • Calcium intake **Other:** • Distance between aorta and vertebrae • Vital capacity

The authors stated that as a result of their best-evidence analysis, they *"were unable to find both strong evidence and a consistent pattern of occurrence for AIS and any of these abnormalities….. The relevance [of the available literature] for understanding the multifactorial [a]etiology of AIS is very limited"* as *"systematic analysis of the best available data showed that several abnormalities that were initially described as associated with AIS in the literature, were classified as not associated with AIS, or as 'insufficient evidence' after the critical evaluation."* They also reported that *"For most of the reported anomalies it remains unclear whether they occur during the development of scoliosis simultaneously with the spinal curvature and to what extent they also occur in scoliosis with a known cause, such as congenital and neuromuscular scoliosis. For multiple abnormalities….significant correlations with Cobb's angle or other severity measures has been documented, suggesting that they occur as a result rather than the cause of the deformity."*

Subsequent studies examining some of the areas highlighted by Schlosser et al (e.g. vestibular morphometry) again suggested differences between AIS and non-AIS populations [51]. However, they have done little to refute the overall conclusions and, to date, no definitive cause(s) of AIS has been identified.

One possible factor that has been mentioned in the literature as potentially being involved in the aetiology of AIS but has not as yet undergone any serious study, is that of altered body schema. This topic will form the basis of the next chapter.

2 What is body schema?

The previous chapter described AIS and the uncertainties regarding the mechanisms and aetiology of the condition.

This chapter will define what is meant by the term body representation, in particular the representation commonly referred to as body schema, which has been suggested as a potential factor in the development of AIS. It will describe its role and how it relates to other representations of the body such as body image.

It will then look at disruptions to the body schema that have been reported as a result of injury, experimentally-induced illusions and chronic pain conditions. The changes seen in these examples indicate that it is possible to induce alterations in body schema.

The chapter will conclude by discussing changes in body schema during adolescence and how this may be implicated in the development of AIS.

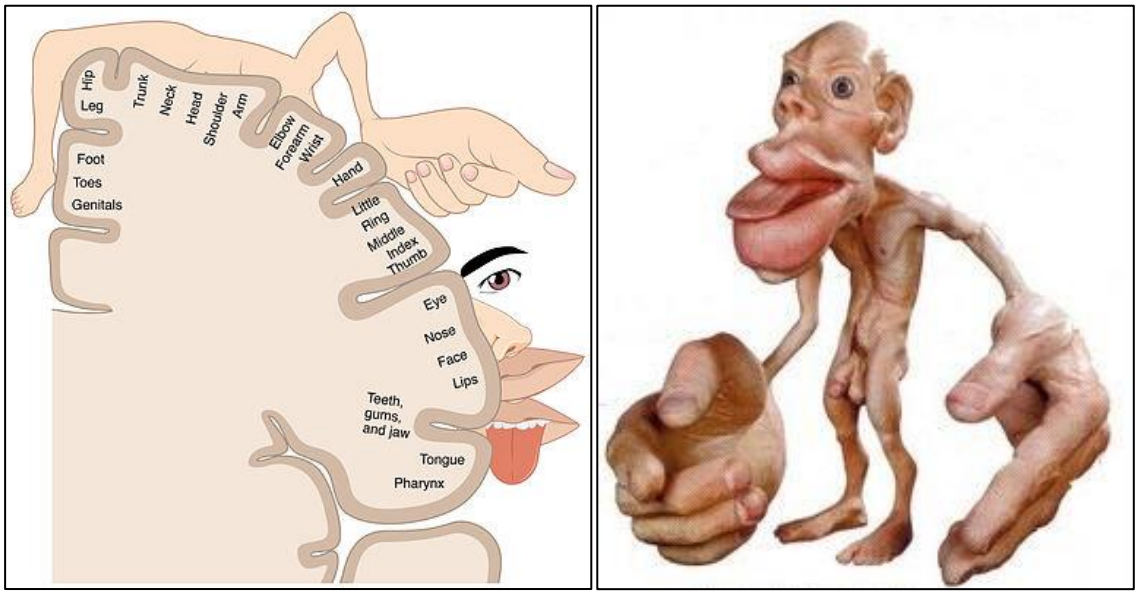
2.1 Body representations - 'bodies-in-the-brain'

In order to function and perform physical actions in the external environment, as well as have some sense of self-embodiment or self-awareness as a physical being, it is necessary for the brain to have knowledge of all the constituent parts that go to make up the body, their form, location and how they interact and move in relation to each other, and their position both in relation to every other part of the body as well as to the external space/environment in which they operate. This knowledge is provided by afferent information from every kind of sensory receptor, as well as copies of the efferent information directed to the muscles that cause us to move. Thus, the continual bombardment of sensory input allied with the cycle of movement and response provides a constant flow of information about the state of our body which is continually updated to reflect the actions and reactions that occur.

All this information is combined and integrated within multiple diverse parts of the brain allowing the construction of various types of body representations or body 'maps' corresponding to different functional and cognitive requirements. At its most basic level, these maps provide a blueprint for the distribution of sensory receptors in the periphery. For example, by stimulating distinct regions of the primary somatosensory cortex (S1) in conscious

patients and registering which body part they could 'feel' being touched, Penfield was able to construct a sensory map linking each section of S1 to its corresponding body area, giving rise to 'homuncular man' (Figure 2.1) [1]. Similar motor maps were produced from the primary motor cortex. Evidence of other maps or 'bodies-in-the-brain', displaying their own stereotypical distortions, comes from a variety of investigations of sensory perception [2].

Figure 2.1 Penfield's sensory Homunculus illustrating how body parts are represented in the primary somatosensory cortex.



(from [3])

Results from neurological and psychological studies suggest that primary information from these low-level body maps is integrated and processed further in other areas of the brain creating higher-order internal representations of the body. They *"differ from primary maps in providing a supramodal, coherent scheme for body representation and skilled action"* [4] and play a vital role in activities as diverse as movement planning, determining location of sensory input and judgements related to body size and shape [5]. The fact that we view our bodies in a more conventionally proportioned manner than that of the 'deformed' primary maps is one indication that these higher level representations are at work [2].

Investigators have proposed a number of distinct higher-order body representations, each responsible for a different aspect of how the body is represented in the brain. These include

how we perceive our body with regard to physical location and posture as well as the emotions, beliefs and attitudes towards our body in particular and the knowledge we have about bodies in general [6].

2.1.1 Models of body representation

The most commonly described body representations are the body schema, body image and the body model (or structural description of the body) and together they constitute what is generally considered the standard model. However, attempts to define them, in particular what they constitute, their respective boundaries and how they inter-relate with each other and other aspects of the brain and behaviour, has been the subject of much debate.

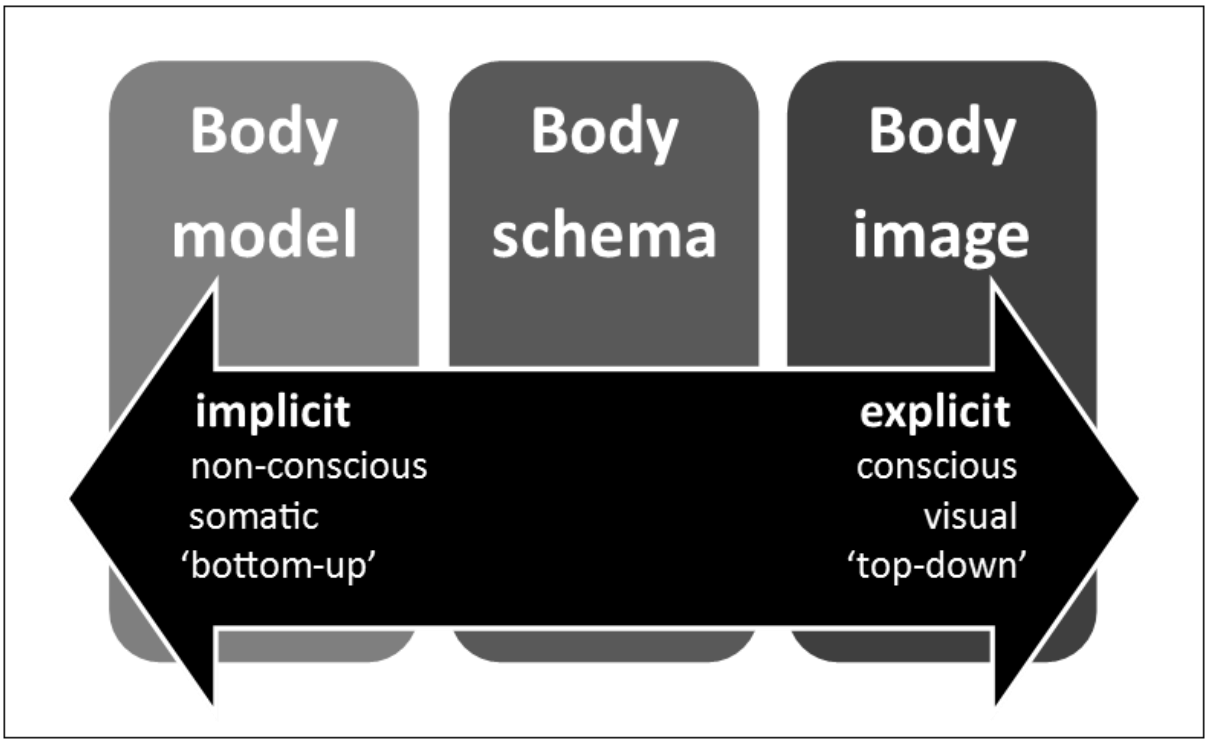
To make matters worse, a range of authors have used distinct terminology to describe broadly similar ideas. Even when common terminology has been utilised, the concepts they describe can be significantly different, while at other times terms have been used interchangeably (particularly, body schema and body image) [7]. Some authors have further subdivided these categories into smaller and smaller classes of representations or postulated alternative separations based on different criteria (e.g., functional role, temporal characteristics, sensory weighting) [8].

Part of the problem is that reductionist approaches, based on detecting ever new forms of body representation, could theoretically lead to an almost infinite number of 'separate' representations as the brain can be damaged (or in the case of intact brains, 'fooled') in a myriad of ways with a virtually unlimited number of possible resulting deficits [9]. This has prompted calls for some form of rationalisation. As a result, two alternative methods of conceptualising the manner in which the body is represented in the brain have been proposed.

One view of the standard model argues for a division based on implicit (non-conscious, action oriented) versus explicit (conscious, cognitive) body representations. However, rather than a dichotomous relationship, implicit and explicit representations should be considered as different ends of a single continuum. At the implicit end of the continuum lie the lower-order body maps (e.g., those in the primary somatosensory cortex) and the body model, while at the other end is the conscious experience of the body *"…as a coherent volumetric object in the world"*, i.e., the 'explicit' body image (Figure 2.2). Higher order body representations along the continuum will be characterized by different weightings of afferent information (e.g., visual,

tactile or proprioceptive) [10]. This model recognises the generally accepted view that although described as distinct entities, the different types of body representations are closely related and highly co-ordinated systems [10]. Each of them is related to a specific cognitive or functional need, and normally they operate in an integrated manner to provide an overarching neural representation of the body. However, observation of deficits that occur following brain injury, as well as studies in normal uninjured people "…*has unearthed the fault lines in the system, thereby permitting the modularity of the representations to be recognised"* [5].

Figure 2.2 Body representation continuum



(based on [2, 10])

Similarly, another recent proposal aims to combine the different representations into a unified 'body matrix' [11]. This adopts Melzack's idea of a neuromatrix, *"…a distributed but functionally integrated brain system that acts as a whole and produces a feeling of the body as a unity, though with different qualities at different times"* [12]. The body matrix model aims to avoid the potentially complicated scenario of an infinite number of 'bodies-in-the-brain' by defining all the possible different representations as multiple aspects of one overarching construct. It incorporates the sensorimotor body schema and the conscious evaluative body

image as parts of an overall network that extends to include homeostatic function (e.g. thermoregulation) and the space immediately around the body, and which serves to maintain the integrity of the body both physically and psychologically. The body is therefore defined by multiple cortical representations, all of which combine to form the body matrix [11].

A full evaluation of all the issues surrounding the classification of body representations is beyond the scope of this discussion. However, the concepts of body schema and body image in particular are still widely accepted, appear to have a neurophysiological basis and serve as useful ways of thinking about at least some of the ways the body is represented within the brain which are of particular relevance to this thesis. Therefore, it would be beneficial to describe some of the history of the development of our knowledge of these neural representations of the body and to provide some working definitions of the concepts that will be investigated further in this and subsequent chapters. In particular, the concept of body schema, body image and the body model will be discussed.

2.1.2 Body schema

In the 1890's, the physiologist Hermann Munk was one of the earliest to consider how the brain was capable of establishing the body's posture and position in space. He pictured a series of movement 'images' stored in memory, based on afferent input produced by active movement and from other sensory inputs such as touch. This concept was adopted by the neurologist Carl Wernicke who used the name 'body consciousness' to refer to an awareness of spatial orientation of the body and the location of sensory input [13].

The term 'schema' is thought to have first been introduced by Pierre Bonnier in the early 20th Century and was further popularised by the influential work of Arnold Pick, Henry Head and Gordon Holmes [13]. They suggested that a number of schema (or schemata) existed to account for different representations of the body. For example, Head and Holmes defined a 'postural schema' as the internal model *"against which all subsequent changes of posture are measured before they enter consciousness……By means of perpetual alterations in position we are always building up a postural model of ourselves which constantly changes."* [14].

A further schema was concerned with the localisation of tactile input to the skin. The description of this resulted from observations of neurological patients who could not localise the site of tactile stimulation despite recognising that they had been touched, indicating that a

deficit had occurred in a higher-order representation. They suggested that the affected part related to an internal body map or schema specific to localisation of sensory stimulation of the skin which they termed the 'superficial schema' [14]. An important aspect to note in Head and Holmes' description of these body 'schemata' are their unconscious nature, i.e. they operate at a level below that of conscious awareness.

Current descriptions of body schema owe much to the earlier work of Head and Holmes and focus on its essential role in movement. It is commonly defined as a system of sensory-motor processes that constantly regulates posture and movement and operates without awareness or the necessity of conscious monitoring [7]. This body schema integrates proprioceptive, motor and homeostatic functions with perceptual and sensory functions to provide the brain with an on-line dynamic representation (or map) of body configuration [15] and a frame of reference allowing the execution and constant monitoring of movement and postural control [16].

This allows the brain to know where each part of the body is at any one time, both in relation to other parts of the body and the external environment. This is an essential first step in motor planning as, in order to move, it is essential to know the starting point from which movement will occur. Secondly, it allows the performance of movement without the need for conscious attention to each step of the movement itself, allowing the brain to concentrate on other more important tasks. For example, in order to pick up an object, the brain is able to focus its *conscious* awareness on the object itself rather than the series of movements, postures and actions that occur unconsciously throughout the body to place the hand in the required position to grasp the object. Without a body schema, maintenance of posture and the performance of movement would require conscious step-by-step planning for even the most basic of movements [17].

Other fundamental properties ascribed to body schema include coherence and adaptability. The former ensures a coherent picture or map of the body even in situations of sensory conflict or discrepancies. This struggle to maintain coherence can lead to bodily illusions under certain experimental conditions. The body schema is also able to adapt to account for changes in body shape and size (e.g. growth during childhood) or even tool use [4]. Tools utilised in the performance of tasks can be incorporated into the body schema along with peripersonal space (i.e., the space immediately outside of the body within which actions can be performed). The

limits of this space are determined by the task, body part involved and the type of tool utilised [18].

2.1.3 Body image

As conscious beings, humans have the ability to think about their own body and be consciously aware of its presence. These thoughts can be influenced by other cognitive processes (e.g. emotions) such that our perception can be 'coloured' to a greater or lesser extent. This ability has been broadly encapsulated by a higher-order body representation commonly described as the body 'image' [19]. As opposed to the largely non-conscious online map of the body's physical location and orientation provided by the body schema, body image is concerned more with the conscious perception or image we have of what our body is like. This includes attitudes, beliefs, emotions [7] and an understanding of bodies in general (e.g. scientific knowledge) [20] which ultimately results in how the body is viewed as a physical and biological entity in itself [21]. External factors such as societal and cultural norms can also influence this perception [19].

Some authors have further subdivided body image into distinct components (e.g. body percept, body concept, body affect) to account for the various aspects described above [5, 7] but for the sake of simplicity, within this thesis they have been all grouped under the concept of body image. Other authors have also included knowledge of the names of each body part and their functions (i.e. how they are used or 'work') as part of the overall concept of body image [16].

One of the key features of body image is the issue of consciousness. In general, body schema is thought to operate below the level of consciousness whereas body image is thought to be a conscious construct (implicit versus explicit in accordance with Longo's model). This has led to the description of body image as a more abstract representation, heavily influenced as it is by other cognitive processes, as opposed to the more 'concrete' map of physical locations provided by the body schema [20].

The weighting of sensory input is also thought to be different. Non-visual input (e.g., proprioception, kinaesthetic, somatosensory, vestibular) is likely to be of greater importance for the body schema as it provides direct information on position and dynamics of the body. In contrast, visual input is often suggested as a key driver of body image [7, 13, 22].

2.1.4 Body model / structural description

Alongside the classic dualistic model of body representation described by the body schema and body image, some authors have proposed a third category referred to as the body structural description [5] or body model [2]. This contains information regarding the physical structure of the body and how it is organised anatomically, including information regarding metric properties (e.g., length and shape). The rationale behind this concept is that afferent information from muscle, joint and other peripheral structures provide information regarding joint angles (i.e., the position of one body part relative to another) which is insufficient to locate each part in external space. Information regarding the length of body segments is also required. As there are no receptors that provide such data, investigators have suggested a separate system that stores these details about the body [2]. The body model is also thought to contain information regarding the available range and degrees of freedom of movement for each joint, i.e. how far and in what directions it is possible to move each joint.

In summary, the terminology associated with body representations is still open to debate and definitive models have yet to be established. However, the concept of a representation that encompasses what has commonly been called the 'body schema' serves as a convenient way of defining and testing the underlying properties that this thesis is seeking to investigate. Therefore, the term body schema, and the definition provided above, will be used throughout as short-hand for the type of body representation this thesis has set out to investigate with relation to its possible association with the development of AIS.

2.2 Disruption of body schema

Evidence to suggest that body representations such as body schema can be disrupted is provided through various distinct methodologies. Examples include abnormalities that may occur after neurological damage (e.g., deafferentation, phantom limbs), experimentally-induced illusions such as the rubber hand and nose lengthening illusions, and chronic pain conditions.

2.2.1 Deafferentation

Although rare, cases where people have lost virtually all sensation provide an extreme example of disruption to information that is vital to construction and updating of the body schema as

well as an excellent insight into the importance of the body schema in normal functioning and movement.

In probably the most famous case of deafferentation, a person suffered a large diameter sensory neuropathy following a viral illness resulting in complete loss of proprioceptive, kinaesthetic and tactile sensation from the neck down [17]. Motor commands and sensory information conveyed by small-diameter fibres (e.g., nociception, temperature, muscle fatigue) remained unaffected, along with visual and vestibular input. This left the patient in a 'disembodied' state in that their body effectively 'disappeared' if they closed their eyes or turned off the light at night (causing them to collapse or fall). Without visual input, they could not determine location of their body parts in space or in relation to other parts of their body, nor could they sense tactile stimulation. The lack of necessary background information provided by proprioceptive, kinaesthetic and tactile sensory input effectively extinguished the normal body schema, resulting in almost complete reliance on the visual, and to a lesser extent, the vestibular systems to provide information regarding where the different parts of the body were in relation to each other and the external environment.

This had profound implications for motor planning as in order to move, they must be able to see the relevant parts of the body at all times requiring continuous visual and mental concentration. As well as the desired movement, they must also take into account, and consciously control, the compensatory actions required in order to make the movement possible (e.g. shifting body weight and altering posture to compensate for moving the arm). Maintaining any posture, apart from lying down, is a task rather than an automatic process [17].

Initially, the patient had no control over their movement. Over time, and in contrast to other people who had suffered similar injuries, they regained a high degree of function although movements were slow and not smoothly performed [17]. In this case, each individual element of an action has to be planned and actively attended to (including compensatory actions to maintain stability) as part of an overall movement sequence, in contrast to the automatic, non-conscious nature of most normal movement. The lack of automatic processes previously dealt with by the body schema resulted in movement being limited in a number of ways:

1) the limited number of items to which attention can be paid at any one time mean that not all aspects of movement can be attended to. Any distractions limit this still further or render movement impossible.
2) the need for conscious planning and monitoring of movement slows the process down resulting in an inability to perform rapid movements and tasks that require rapidly alternating and repetitive movement (e.g. brushing teeth).
3) the mental effort required to perform even the most basic movements limits the duration of motor activity.
4) activities that require more than one task to be performed simultaneously (carrying an egg while walking) or that involve complications imposed by the external environment (walking over rough ground) are intensely difficult and require more concentration and energy to perform [17].

In this unique case, the patient has been able to reconstruct a limited form of the body schema, one which relies almost exclusively on visual perception to replace the lack of proprioceptive and other sensory input. However in most cases of deafferentation, people are unable to rebuild the body schema to any extent, preventing the performance of functional movement and normal activities (e.g. walking) almost entirely. These examples vividly illustrate the vital role body schema plays in normal function whilst demonstrating the maximal disruption possible, i.e., a 'missing' or disabled body schema.

2.2.2 Phantom limbs

The phenomena of phantom limbs provides another example of dysfunctional body schema following neurological damage. They may occur following limb amputation, deafferentation or spinal cord injury (SCI) [20]. In such cases, the body schema fails to adapt to changes in the structure of the physical body. Phantoms can also occur in aplasia, the congenital absence of limbs, suggesting that the body schema is to some extent innate [23]. However, the fact that they are more common when amputation occurs in adults as opposed to children, suggests that the body schema may become more entrenched with time.

Phantom limbs are generally perceived to occupy space and to adopt postures characteristic of the 'lost' limb (e.g. in SCI, the lower limbs are often perceived as extended at the knees and slightly flexed at the hips) although they may also occupy unrealistic or even anatomically

impossible postures [20]. Often, the position of the phantom reflects the last seen position of the actual limb prior to injury. People with phantom limbs may also modify their interaction with the environment to accommodate the presence of the phantom (e.g., making extra space when moving around, walking through doorways side-on) or may perceive their phantom limb as shrinking or disappearing if it 'contacts' external objects [20]. At times, they even attempt to use the missing body part (e.g., a lower limb amputee attempting to walk with the phantom leg), illustrating the extent to which the body schema remains unchanged [7].

Another class of phantom limbs can occur in cases of central nervous system damage. Sometimes extra or supernumerary limbs are perceived although duplication is generally of a physical limb that has been deafferented or paralysed. It is suggested that the presence of supernumerary limbs indicates the brain's attempt to reconcile differences between copies of efferent movement input and proprioception. The mismatch between intended and actual location of the limb causes the brain to conjure up an extra limb in order to account for the two perceived locations, thereby maintaining a coherent representation of the body [20].

The example of deafferentation and phantom limbs described above are illustrations as to how the body schema is able to be disrupted following injury and that this disruption can take various forms, and have different consequences, depending on the nature of the injury itself.

2.2.3 Bodily illusions

As well as changes described above following neurological damage, temporary disruptions in the body schema can be induced in normal healthy people under certain experimental conditions. By generating a mismatch between different sensory streams, a change in the body schema is produced creating a bodily illusion, such as the Rubber Hand or the Pinocchio illusion. These demonstrate the plasticity of the body schema.

2.2.3.1 Rubber hand illusion

In the rubber hand illusion, volunteers sit at a table with a sheet or similar placed so that one forearm or hand remains visible and the other is hidden. A rubber limb is placed in position to mimic the hidden hand. Simultaneous stroking of the rubber and hidden hand induces the perception that the rubber hand is in fact their real hand (Figure 2.3). In this case, the combination of visual and tactile sensation overcomes proprioceptive information and causes the artificial limb to be incorporated into the body schema. Evidence that the fake hand is

incorporated is provided by the increase in stress response recorded when a threat to the fake hand is perceived (e.g., hitting the fake hand with a hammer) [24].

The illusion is most effectively evoked when the fake hand is in an anatomically feasible position, in close proximity (within 30 cm) and orientation to the actual hidden hand, and when the same tactile stimulation is applied in a synchronised manner to both hands, preferably with random and unpredictable timings. However, it is not necessary for the fake hand to closely resemble the real hand [20]. It has also been suggested that the fake hand does not even need to be visible - the act of seeing the fake hand being covered up is enough once appropriate tactile stimulus is applied to both real and fake hands.

Blindfolded subjects can even induce the illusion themselves by stroking the rubber hand whilst the real hand is synchronously stroked by someone else [20].

Figure 2.3 Rubber hand illusion

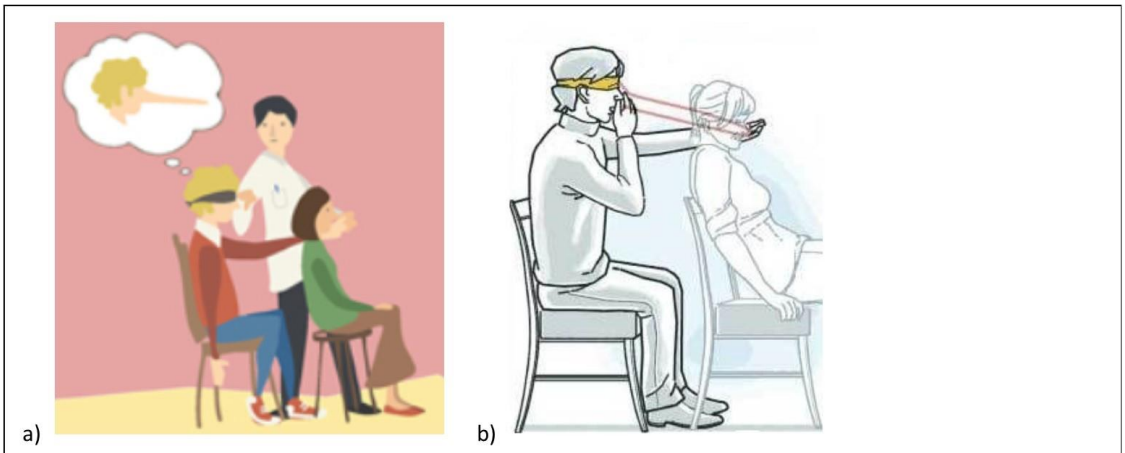
Fake rubber hand (left) and the hidden actual hand (right) are stroked simultaneously.

2.2.3.2 Pinocchio illusion

In the Pinocchio or nose-lengthening illusion, a blindfolded subject is positioned behind another person. The subject taps the nose of the other person whilst their own nose is tapped simultaneously by either the other or a third person (or in some versions, the subject themselves) (Figure 2.4). Without the corrective effect of vision, the subject perceives that the tip of the nose is further away than normal and thus, that the nose has increased in length [20].

A modified version of this involves the subject holding their own nose while the biceps tendon is subjected to mechanical vibration. Normally this would result in reflex flexion of the elbow courtesy of the tonic vibration reflex. However, if the motion of the arm is physically restrained, the majority of subjects perceive their nose, fingers or both as elongating. By preventing reflex flexion of the arm, the brain perceives apparent extension – as the fingers remain in contact with the nose, either the nose, fingers or both 'must' be lengthening. Conversely, vibration of the triceps tendon results in the opposite effect with subjects reporting their nose shortening (to the extent of being pushed inside their heads), their fingers passing through their nose to be located inside their head, or their head being pushed backwards (figure 2.5). The tendon vibration alters proprioceptive input regarding joint angles, inducing the feeling of movement and resulting changes in the body schema and the perceived shape and orientation of the body [25].

Figure 2.4 Pinocchio illusion



With the subject's nose being tapped by either a) the experimenter (left) or b) the subject themselves (right).

(from: a) [26]; b) [27])

Similar illusions using tendon vibration have been used to induce the sensation of shrinking or expanding waist lines, altered neck or limb length, and altered posture or orientation of the body itself [25]. These illusions again demonstrate how the brain attempts to maintain a coherent body representation, often with bizarre consequences.

Overall, these illusions suggest that body schema is highly labile and, depending on the nature of sensory input, the internal representation of the body can be disrupted temporarily even to the point of accepting physically impossible postures or fake body parts.

2.2.4 Chronic pain conditions

Although a distinct class of conditions, chronic pain states such as phantom limb pain (PLP), chronic regional pain syndrome (CRPS) and chronic low back pain provide a useful conceptual model for body schema in AIS. There is increasing evidence that central nervous system (CNS) changes play a major role in the pathogenesis and maintenance of chronic pain states and that disruptions to body representations such as body schema have been associated with these conditions.

As this thesis is concerned with AIS, which primarily involves changes to the trunk and spine, this overview will focus on studies examining body schema in chronic spinal pain. It will discuss the evidence for both cortical and perceptual changes that are thought to underlie disruptions to cortical body representations in chronic low back pain, as well as treatment strategies aimed at reversing the alterations and, ultimately, restoring body representations including body schema.

2.2.4.1 Cortical changes

Numerous studies have reported cortical changes in chronic pain conditions such as CRPS and PLP. Similarly, studies using a variety of brain imaging techniques have reported reorganisation of the somatosensory and motor cortices in chronic low back pain (CLBP), with the cortical area representing the lower back expanding to invade other nearby areas (e.g., the area representing the leg). This induces a ‘blurring’ of the boundaries of the representation of the lower back region within the cortex. The degree to which this occurs appears to be related to the duration of symptoms [28]. Cortical maps of individual sub-regions of the lower back have also been shown to lack definition, indicating that the ‘blurring’ described above is not

confined to the boundaries but may involve the entire lumbar cortical representation in patients with CLBP [29]. This has implications regarding the ability to pinpoint the location and properties of sensory input from these regions. Similarly, a shift in the cortical representation of individual spinal muscle groups resulting in overlapping or 'smudging' has been reported in LBP patients [30]. The magnitude of these changes appears to be associated with the severity of LBP symptoms [31] and may compromise the ability to control discrete muscle groups separately. Although it is unlikely that these changes are the cause of LBP, there is evidence to suggest that they contribute to the development and maintenance of chronicity [28].

As well as these organisational changes, there have also been reports of neurochemical and structural changes in the cortex associated with CLBP in comparison with non-LBP controls. These include altered neurochemical profiles and reduced grey matter in various brain areas, the magnitude of which have been reported to correlate positively with pain duration and/or intensity [32, 33].

The changes in cortical organisation do not appear to be confined to nociceptive input. A recent fMRI study of non-painful mechanical stimulation of the lumbar spine also revealed maladaptive changes in higher-order processing of sensory information and cortical representation of the lumbar spine in patients with CLBP when compared to controls. They concluded that these changes may affect body perception with subsequent effects on the functioning of the spine [29].

2.2.4.2 Perceptual changes

The cortical changes described above are manifested by changes in the way the spine is perceived by people with CLBP. Tactile acuity (i.e. the precision with which we are able to judge different properties of touch) has been a topic of particular attention. A systematic review evaluated different aspects of tactile acuity in patients with chronic pain [34]. The pooled results from four studies which measured two point discrimination thresholds (TPDTs) suggested that they were larger in CLBP patients as compared to controls indicating worse tactile acuity (mean difference 11.7mm, 5.5 to 17.8mm 95% CI; % difference 26%, 12 to 39% 95% CI; effect estimate 1.14, 0.54 to 1.74 95% CI, p=0.0002). These results were confirmed by a more recent systematic review involving 19 studies [35].

This affect appears to be specific to the painful area. Three studies measured TPDTs on either side of the spine in patients with unilateral CLBP. The pooled results suggest that the threshold for detection of two point stimulus was larger on the affected versus the unaffected side (mean difference = 1.4mm, 0.7 to 2.0mm 95% CI; % difference = 58%, 29 to 86% 95% CI; effect estimate 1.85, 0.95 to 2.75 95% CI, p<0.00001). This finding is further supported by a study which looked at forearm TPDTs and found no statistically significant differences between CLBP patients and controls [34].

Investigations of other properties of tactile acuity have also reported deficits in CLBP patients, for example in localisation of stimulus and temporal order judgement (judging which stimulus was applied first when two asynchronous stimuli are applied to either side of the spine) [36].

Alterations in standing balance, laterality discrimination (judging direction of trunk movement from a series of pictures of the trunk in various postures) [36], postural control [37], proprioception and difficulty delineating the outline of associated body segments [32] are among other perceptual changes that have been reported in this patient population. This latter finding appears to relate to painful regions of the back which exhibit reduced tactile acuity [36]. Some patients even report that they have difficulty locating or 'feeling' the presence of their back [38].

Caution should be taken with interpreting these results as, in general, most studies had small sample sizes and are likely to be underpowered. However, taken together, these alterations in perception provide further evidence of changes in the way the body is represented in the brain and highlight the various sensori-motor manifestations that occur as a result of these changes.

2.2.4.3 Treatment

Approaches to address altered body schema in CRPS and PLP, using programmes aimed at activating cortical motor and pre-motor networks, have shown promise with resolution of symptoms and normalisation of neurophysiological findings [38] including brain changes [37, 39, 40]. Interventions used include tactile discrimination and laterality recognition training as means to achieve these changes. The basic premise common to all these programmes is the attempt to `reformat' or rewire the brain's internal body maps. In comparison, very few studies have investigated the use of similar approaches in CLBP.

One study investigated the use of a motor skill training programme which involved isolated voluntary contractions of transversus abdominus (TrA) in patients with recurrent LBP [37]. This was in response to previous work which suggested alterations both in the motor performance and the cortical representation of TrA in the motor cortex in LBP patients [41]. After two weeks, the motor skill training group (n=10) experienced a shift in the cortical representation of TrA towards the location observed in healthy non-LBP participants. Importantly, these changes were reflected by improved motor performance of TrA. Neither of these changes were observed in the control (self-paced walking) group (n=10).

The lack of any statistically significant differences in pain scores between groups, nor any change in symptom-related function scores pre-post intervention, calls into question the role of TrA in recurrent LBP, although longer time-frames may be required to see any effect. However, the study does reveal that programmes targeted at optimising motor behaviour (in this case, a type of motor 'discrimination' training) can induce favourable reorganisation of the motor cortex and reveal reversibility of earlier maladaptive changes.

Using an approach more akin to that used in previous CRPS and PLP trials, a single case experimental design was conducted with three participants suffering from CLBP [42]. An initial baseline monitoring period of up to 5 weeks was followed by at least 10 weeks of an individualised, progressive sensori-motor training programme. Data was collected weekly during the intervention period and for one month post-intervention. The intervention consisted of localisation training (determine location and type of stimuli applied to lower back region), graphesthesia training (identification of alphanumeric figures 'traced' on back), laterality recognition (identifying side or direction of trunk movement from a series of images), and motor training using a graded approach as described in Figure 2.5.

All three participants reported reduced pain intensity, pain interference and disability during the intervention and this effect was maintained for at least one month once treatment had finished.

Two other case studies [43], plus a cross-over trial (n=25) which used acupuncture as a form of sensory discrimination training [44], also reported positive effects using strategies targeting cortical reorganisation.

Although only a preliminary step in evaluating the use of this type of intervention in CLBP, these results are consistent with those found in previous studies of other chronic pain conditions, and indicate that treatments aimed at reversing changes in the cortical representation of the lower back, as well as sensory and motor discrimination ability may be successful in treating this condition.

Figure 2.5 Training programme for CLBP as used by Wand et al 2011

Summary of the Retraining Program[a]

Stage	Sensory Retraining	Motor Retraining
1	Localization training	Laterality recognition
	Determine site of stimulus	Using Recognise software[b]
	With visual feedback during first week	Determine whether left or right side of back
	Without visual feedback during second week	Progress by time for which image was presented
2	Localization and stimulus type	Imagined movements
	Determine site of stimulus	Using video of model performing movements
	Determine size of probe	Small-range movements during first week
	Progress by adding points	Full-range movements during second week
3	Graphesthesia training	Isometric local muscle recruitment
	Recognize letters	Transversus abdominis muscle
	Progress by size	Lumbar multifidis muscle
	Progress by orientation	Co-contraction with pelvic floor
	Progress by speed of drawing	Dissociation exercises
4	Graphesthesia training	Small-range movements with feedback maximized
	Recognize 3-letter words	Visual feedback with mirrors
	Progress by size	Intersegmental palpation[c]
	Progress by orientation	Tactile feedback from elastic tape
	Progress by speed of drawing	Repositioning training
	Progress by overlapping letters	Moving with respect to external reference
5	Graphesthesia training	Full-range movements with feedback maximized
	Calculate simple sums	Visual feedback with mirrors
	Progress by size	Intersegmental palpation[c]
	Progress by orientation	Tactile feedback from elastic tape
	Progress by speed of drawing	Repositioning training
	Progress by overlapping numbers	Moving with respect to external reference

[a] Each stage was planned to last a minimum of 2 weeks.
[b] Neuro Orthopaedic Institute, 19 North St, Adelaide City West, South Australia 5000, Australia.
[c] Performed by the participant.

Since these initial attempts, a number of studies have been conducted on this topic. Six of these were included in a systematic review of RCTs looking at sensory discrimination training (SDT) for CLBP [43]. The results suggested that while SDT improved pain and function in people with CLBP, due to the small sample sizes (maximum n=60) and heterogeneity of treatment approaches used, the authors were not able to make any conclusive determination of its

effectiveness compared to other forms of treatment. It should be noted that 5 of the 6 included studies used very different treatment modalities to the case series reported above, which followed similar methods to those in previous studies of CRPS and PLP. The single study that used a comparable approach was a pilot study that relied largely on a home-based intervention with 'carers' conducting the intervention. The small initial sample size and high drop-out rate, particularly in the control (placebo) group, may have been key factors in the lack of difference found between groups in this trial [45]. The lack of definitive evidence found by the authors of this review echoes the findings of an earlier review that investigated all treatment methods targeting cortical remapping in CLBP [46]. They also reported methodological problems with the majority of studies included and commented on the paucity of high-quality trials available for evaluation. In-line with the recommendations of both these systematic reviews, it is hoped that further evidence as to the effectiveness of SDT and other cortical remapping strategies in CLBP will be provided by larger, better-powered studies such as that proposed by Walti et al [47] or the RESOLVE trial currently underway [48].

2.2.4.4 Implications for body representations

In summary, the discussion of the literature relating to CLBP and body representations highlights that:

1) there is direct evidence from brain imaging studies that in the presence of CLBP, the sensori-motor cortices associated with the spinal region undergo reorganisation.

2) this is supported by perceptual alterations that are associated with both the changes in the cortical representations as well as pain intensity and chronicity of CLBP. The fact that these perceptual changes cannot be explained by deficits in sensory detection or transmission, as well as the range of sensory inputs affected, provide further evidence that they are manifestations of cortical reorganisation involving the representations of the spine in the brain [34].

3) The final key plank linking CLBP and brain disruption relates to treatment strategies aimed at reversing the perceptual changes and cortical reorganisation. Taken overall, to date there is little evidence for interventions that aim to achieve these goals. However, in the few preliminary studies that have mimicked the interventions used in successful trials of other more-studied, chronic pain conditions (e.g. CRPS, PLP), similarly favourable outcomes have

been achieved. Caution in extrapolating these findings needs to be taken until stronger evidence is provided, but they do suggest that appropriate, specifically targeted therapies may be successful in CLBP as they have been in these other chronic pain conditions.

Together, these findings suggest that CLBP involves alterations of lower-level body maps as well as higher-order sensory processing with implications for body representations, particularly the body schema, and the functioning of the lower back [29]. Impaired control of muscle tension has been associated with chronic pain conditions [36] and, along with other motor abnormalities observed in CLBP, suggest how an altered body schema may affect the spinal musculature [30,31,32], an important consideration in the following discussion of how a disrupted body schema may be implicated in AIS.

2.3 Body schema in adolescence

The ability of neonates to imitate facial expressions and gestures suggests that body schema is innate due to the coordination of visual and tactile-kinaesthetic information required to recognise and then reproduce a movement. As mentioned previously, further support for an innate body schema is provided by the presence of phantom limbs in some children with a congenital absence of limb and therefore, who have never experienced the actual limb as part of their physical body [7, 22]. During the progression through childhood to adolescence and early adulthood, the body schema gradually matures with greater experience and integration as both the body and the brain undergo different stages of growth and reorganisation.

Adolescence is a critical period of growth in which rapid changes occur in body size, shape and composition over a relatively short period of time. It is also a time when the brain undergoes a major phase of maturation involving synaptic ‘pruning’ and myelination, and consequent reorganisation of cortical networks [22]. It has been suggested that the rapid physical changes of the body outpace the development of the corresponding body schema resulting in systematic mislocation of body parts in space [21], evidenced by the ‘clumsiness’ and lack of neuromuscular co-ordination characteristic of adolescence. Findings from studies investigating body schema development suggest that it does not fully mature until early adulthood.

As previously described, the body schema, with both sensory and efferent motor input, plays an important role in motor planning and acts as an interface between perception and action.

Using various methodologies (e.g., postural disturbance, motor imagery, illusory movement), it is possible to establish its efficiency and effectiveness in performing this role across different age groups. The results of these studies revealed notable differences between adolescents and young adults on both a postural and perceptual level [22], suggesting that the body schema undergoes a long maturation process throughout adolescence and into early adulthood. Reports that development of the body schema tended to occur 1-2 years earlier in girls is consistent with the earlier onset of puberty and physical maturation in females [49].

It is also interesting to note that in studies looking at dynamic proprioception and postural control, it was principally the trunk area that was disturbed in adolescents in comparison to adults, indicating a *"…transient loss of reference point, which was probably linked to a disturbance of body schema*." This is consistent with peak proprioceptive ability not being achieved until early adulthood making it difficult for adolescents to control their movements by proprioception alone (i.e., without visual input) [22].

The fact that the trunk was the region exhibiting the greatest lack of control may be significant when considering the potential role of a dysfunctional body schema in adolescent idiopathic scoliosis (AIS).

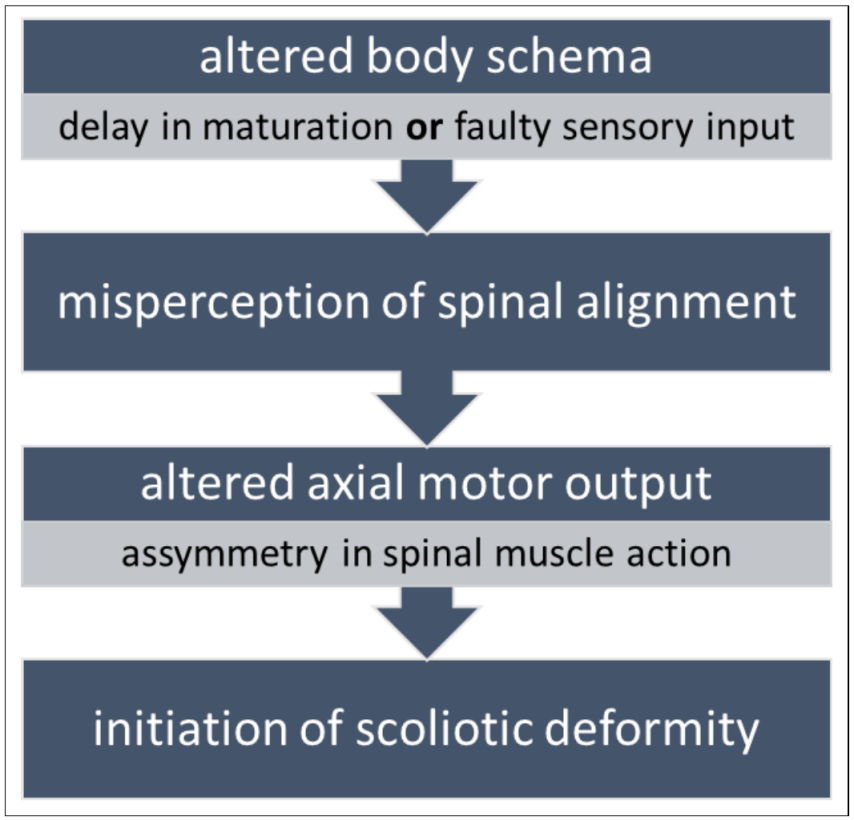
2.4 Body schema in AIS

An alteration or maladaptation of the body schema as part of a sequence of pathological events has been proposed as a possible mechanism in the development of AIS.

Herman et al [50] originally proposed that idiopathic scoliosis was due to impaired neural control of the axial (spinal) motor control system. They suggested that changes in vertebral alignment may result from altered sensory information or *"…by modified perceptual analysis of sensory data describing erect vertebral alignment…the net effect of impaired integration would engender disturbances in vertical orientation of the vertebral spine."* In other words, the sense of upright posture, which is dependent on normal integration of visual, vestibular and proprioceptive feedback, is altered such that the brain perceives non-erect vertical alignment of the spine as 'erect' or 'straight' (and vice versa). This is consistent with anecdotal observations that at the time of diagnosis, most patients are unaware that they have a scoliosis despite there being a significant curve or structural deformity [51].

Subsequent motor adaptation of the axial motor system to this altered cortical representation of the body generates an asymmetry in muscle forces applied to the spine [50, 52]. It is not clear whether this is sufficient on its own to cause the structural deformation characteristic of scoliosis, or if it merely triggers a process where growth and biomechanical factors contribute to its progression [53, 54], in which case individual susceptibility may vary depending on other factors [55] (Figure 2.6).

Figure 2.6 Proposed process of scoliosis initiation



It is thought that adolescence is a particularly vulnerable period for such maladaptation due to the rapidly growing and changing musculoskeletal system and large reorganisation of the brain, allied with the late maturation of the body schema as previously described [56]. A delay in the maturation of the body schema, or an inability to keep up-to-date with the pace of change, is suggested to be a precursor to the development of the spinal deformity. From this perspective, the higher incidence of AIS in females may be explained by the earlier and more rapid growth spurt they undergo during adolescence as compared to males [53, 55].

Reported abnormalities of vestibular function [57], perception of vertical [58, 59], proprioception [60-64], postural control (particularly dynamic balance under sensory challenge) [50, 65-74] and other perceptual changes [75, 76] in AIS lend support to the hypothesis of altered sensory input/processing.

Despite these investigations, to date there have been no attempts to directly investigate the role of body schema in AIS. One study which did purport to examine this issue used a template matching protocol where participants diagnosed with AIS were shown a series of line drawings of scoliotic curves progressively increasing from 0 to 50 degrees in the thoracic, thoracolumbar and lumbar regions of the spine [77]. Participants were asked to select the image that corresponded to their perceived spinal alignment in each region and this was then compared to the actual Cobb angle as calculated from x-rays. The authors reported that subjects tended to overestimate the size of the curve in the thoracic and lumbar regions while underestimating curve size in the thoracolumbar region. They therefore concluded that AIS is associated with an altered corporeal awareness of trunk alignment. However, despite the stated aim of investigating body schema, the assessment tool required participants to make a conscious judgement of the alignment of their spine which is more likely to relate to a type of body representation previously defined as body image rather than that of a non-conscious body schema as used and investigated in this thesis.

2.5 Summary

In summary, the terminology associated with body representations is confusing and still ill-defined. However, the concept of a representation that encompasses what has commonly been called the 'body schema' serves as a reasonable way of defining and testing the underlying properties that this thesis is seeking to investigate.

Therefore, for the purposes of this thesis, body schema can be defined as either one of a number of higher-order representations of the body or one aspect of an overall body matrix. It integrates sensory information from somatic, proprioceptive, vestibular, visual and efferent sources, and is responsible specifically for maintaining a sense of where the body is in external space, its orientation and posture as well as assisting motor planning.

Evidence from observational studies using various methodologies indicates that the body schema is malleable and subject to disruption in cases of brain or peripheral nerve damage as well as chronic pain, but also in normal people under certain conditions.

Development of the body schema through childhood and up to early adulthood involves a slow process of maturation. Adolescence in particular appears to be a critical period with rapid changes occurring both in the body and the brain and suggestions that the body schema is unable to keep pace with the speed of these changes.

It has been proposed that this delay in maturation and inability to maintain a coherent body schema at a time of rapid growth might be the trigger that initiates the musculoskeletal changes characteristic of scoliosis via the spinal motor system.

To date, the only study that has sought to directly assess body schema in AIS is of poor quality and does not appear to use appropriate testing methodology. However, there have been reports from a variety of studies of perceptual deficits in AIS that are relevant to body schema. In order to understand this area in greater detail and to determine if altered body schema plays a roles in AIS, it is necessary to evaluate the literature around theses reported deficits.

This issue forms the basis of the next chapter which details a systematic review conducted to elucidate neurophysiological changes associated with AIS and provides a rationale as to why body schema is a potential factor in the development of AIS.

3 Perceptual deficits in AIS - a systematic review

Previous chapters have defined what is meant by the terms AIS and body schema. They have also highlighted that although suggested as a possible factor in the development of AIS, no studies have so far been conducted to investigate this possible link.

One method of assessing a potential link between body schema and AIS is to review the literature regarding neurophysiological changes or deficits associated with AIS that are also important in the construction of the body schema. If these are observed, then it will provide further evidence as to the possibility of alterations in body schema playing a role in the development of AIS.

Therefore, this chapter details a systematic review that was conducted to elucidate neurophysiological changes associated with AIS and which may provide a rationale for the role of body schema in AIS.

3.1 Materials and methods

This systematic review was conducted and is reported according to the PRISMA guidelines [1].

3.1.1 Data sources and searches

The following databases were searched from inception to 14 November 2018 for studies examining neurophysiological measures in people with AIS compared to controls: Medline, EMBASE, PsycINFO, CDAS, CINAHL, PEDro, and SPORTDiscus. All potentially relevant abstracts were screened using the study inclusion criteria and full text articles were obtained for those that appeared eligible. These were assessed by two independent reviewers for eligibility.

The actual search strategies for each database are described in Appendix 1. Hand searches of references from screened full text articles were also conducted.

3.1.2 Study selection

This review targeted observational studies that used case-control and cross-sectional designs to evaluate neurophysiological function in participants with AIS and non-scoliotic control participants. Studies that examined neuro-anatomical or morphological changes, or

musculoskeletal changes attributable to the spinal deformity itself, were not included. The study inclusion and exclusion criteria for this review are described in Table 3.1.

Table 3.1 Study eligibility criteria

Inclusion
All original studies of people with AIS that reported neurophysiological measures (e.g. proprioception, balance, sensation/perception, sensorimotor performance).
Where studies include participants with AIS amongst other diagnostic groups, able to extract AIS-specific results.
Age of participants between 10 years and skeletal maturity (females, approximately 15 - 17 years; males, 16 - 19 years of age).
AIS diagnosed by appropriate clinician based on radiological/MRI imaging
Cobb angle of main curve ≥ 10 degrees using recognised measuring technique (e.g. from radiographic or MRI images)
Must contain a suitable control group (e.g. healthy adolescents)
Peer-reviewed studies published as full-text
Exclusion
Non-AIS scoliosis (e.g. congenital, neuromuscular or syndromic scoliosis)
Studies of genetic, musculoskeletal or neuroanatomical changes or differences (e.g. bone/muscle, brain morphology).
Studies of people with AIS who underwent treatment (e.g. surgery) that may impact on the abnormality being investigated.
Studies written in other languages where an adequate translation could not be obtained

3.1.3 Data extraction

Data regarding participant characteristics (e.g. age, sex, curve size and type, prior treatment), observed variables, testing procedure and results were extracted independently for each eligible study.

3.1.4 Risk of bias

All included studies were assessed for risk of bias at the study level using criteria devised for this review (Table 3.2). These criteria were based on the STROBE guidelines [2], Critical Appraisal Skills Training Programme (CASP) checklist [3], Scottish Intercollegiate Guidelines Network (SIGN) methodology checklist [4], Newcastle-Ottawa case control assessment study scale [5], and a specifically designed tool used in similar reviews [6]. Studies were categorised

as at high, low or uncertain risk of bias according to the information described in the study reports:

- Low risk of bias - if all key bias domains were considered to be low risk
- High risk of bias - if one or more key domains were considered to be high risk
- Uncertain risk of bias - if one or more key domains were considered to be of uncertain risk or unreported.

Table 3.2 Study risk of bias criteria

Selection bias
are cases representative of AIS population?
are controls representative of general adolescent population, and comparable to cases?
Were the same inclusion/exclusion criteria (except for the spinal deformity) used for AIS and healthy adolescents?
Classification bias
clearly established that controls are non-cases (as well as possible)?
Was other pathology excluded that possibly influences the outcome?
Measurement bias
Was the data collection performed in the same standardized way for AIS cases and healthy adolescents?
Were the observers blinded to AIS/healthy adolescent status?
Reporting bias
Free of selective reporting of outcomes?
Potential confounders identified and taken into account?

3.1.5 Data analysis

Where appropriate, data from studies that evaluated the same parameters were combined and meta-analysis performed using Review Manager (RevMan version 5.3). Mean differences (MD) and standard deviations (SD) were extracted for continuous measures and 95% confidence intervals (CI) calculated. Where direct comparison was not possible or feasible due

to different units or different tools to evaluate the same parameter, standardised mean differences (SMD) were calculated.

Clinical heterogeneity was judged on similarities between study protocols, participants and measured parameters. Statistical heterogeneity was evaluated using the Chi^2 test and I^2 statistic, both generated by the meta-analysis programme. The findings were interpreted as follows according to the I^2 statistic (RevMan Handbook]:

- 0% to 40%: might not be important
- 30% to 60%: may represent moderate heterogeneity
- 50% to 90%: may represent substantial heterogeneity
- 75% to 100%: considerable heterogeneity

Random effects models were used if heterogeneity was moderate or above ($I^2 > 30\%$). Fixed effect models were used if there was no clinical and no important statistical heterogeneity. Sensitivity analyses were also performed if heterogeneity was excessive.

Where it was not possible to combine results, a narrative analysis was conducted.

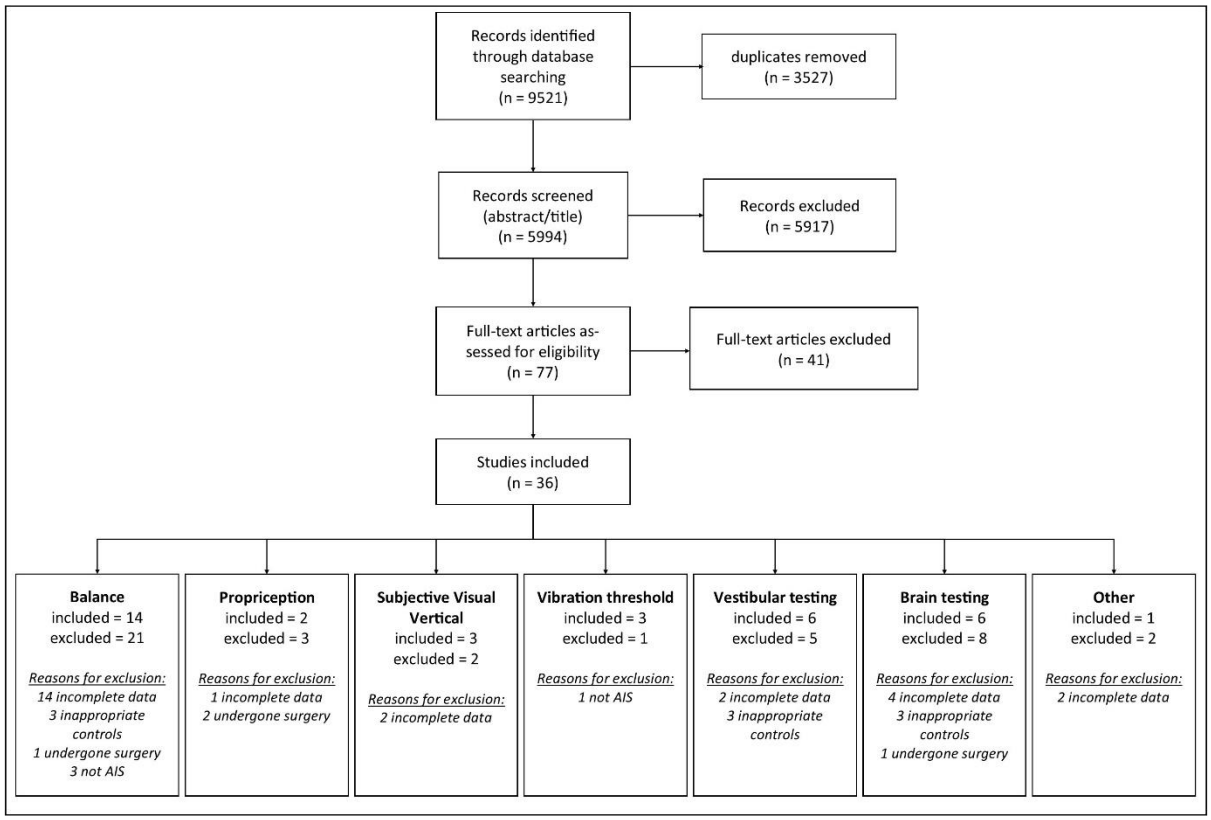
3.2 Results

3.2.1 Search results

Searches of electronic databases yielded 9521 results. After removing duplicates and initial screening of abstracts, 77 articles were retrieved for full text screening. This resulted in 36 studies that met the eligibility criteria and were included in this review (Figure 3.1). The included studies investigated the areas of balance (n=14), proprioception (n=2), perception of vertical (n=4), vibration threshold (n=3), vestibular function (n=6), cortical and nervous system function (n=6) and other forms of perception (n=1) in people with AIS compared to controls.

Due to the diverse nature of the neurophysiological measures evaluated in the included studies, each will be discussed separately.

Figure 3.1 Consort diagram - search and inclusion details



3.2.2 Balance

Thirty-five studies were identified that evaluated balance in AIS and control participants. Twenty one were excluded due to a variety of reasons: 14 studies were excluded to lack of sufficient information to make an accurate comparison [7-20], 3 studies used inappropriate participants as a control group [21-23], 3 studies included participants in the AIS group that did not conform to standard definitions of AIS [24-26], and one study included a significant proportion of AIS participants that had undergone surgery [27]. It should be noted that only studies that measured balance ability rather than parameters associated with postural alignment (e.g. position of centre of pressure) were included.

(i) Characteristics of included studies

Summaries of the included studies are provided in Table 3.3. Studies were conducted in the USA [28-31], Taiwan [32-35], Hong Kong [36], Turkey [37], Canada [38], South Korea [39] and France [40, 41] with sample sizes ranging from 12 [40] to 128 [39] AIS and 12 [40] to 81 [41] control participants. The age of the participants ranged from 7 to 21yrs with mean ages ranging from 11.3yrs to 16.8yrs. Six studies matched participants by age [28, 29, 32, 34, 35,

41]. Five studies only included female participants [28, 30, 31, 36, 38], 5 studies reported the proportion of female participants between 77% to 93% and 64% to 86% for the AIS and control groups respectively [29, 32, 33, 37, 41], and 3 studies did not provide any details regarding female:male ratio [34, 35, 39]. One study included only female AIS participants but did not report details of the control group [40].

Amongst AIS participants, the mean Cobb angle ranged between 17.9 to 39.5 degrees and included participants with Cobb angles ranging from 7 to 67 degrees. Four studies did not provide details of curve type [30, 36, 37, 39], 2 used the King classification system with curves ranging from type I to V [29, 33], 2 studies only included right thoracic curves [40, 41], 3 studies only included double curves [32, 34, 35] and the remaining 3 studies included curves of both directions and various spinal locations [28, 31, 38]. Five studies reported that AIS participants had not received treatment [31-33, 37, 38], 3 studies reported participants had not undergone spinal correction surgery [29, 34, 35], and 4 studies did not provide any details regarding treatment [30, 36, 39, 41]. One study reported that AIS participants had received physiotherapy and bracing [40], and one study reported participants receiving either bracing and/or electrical stimulation [28].

A variety of different balance testing methodologies were used. Eight studies assessed static standing balance using a force plate [28, 31-33, 36-39], one study assessed static sitting balance using a force plate [29], two studies measured dynamic standing balance [34, 35], two studies measured one leg and tandem stance standing times [30, 41], and two studies measured response to an external perturbation in either sitting [40] or standing [35].

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.10. In general, most studies were at uncertain risk of bias across all domains. Specifically, of 14 studies, two studies were considered to be at low risk of selection bias [28, 32], 4 studies were at low risk of classification bias [34-37], 1 study was at low risk [30] and one study was at high risk [40] of measurement bias and all studies were at uncertain risk of reporting bias.

(iii) Results

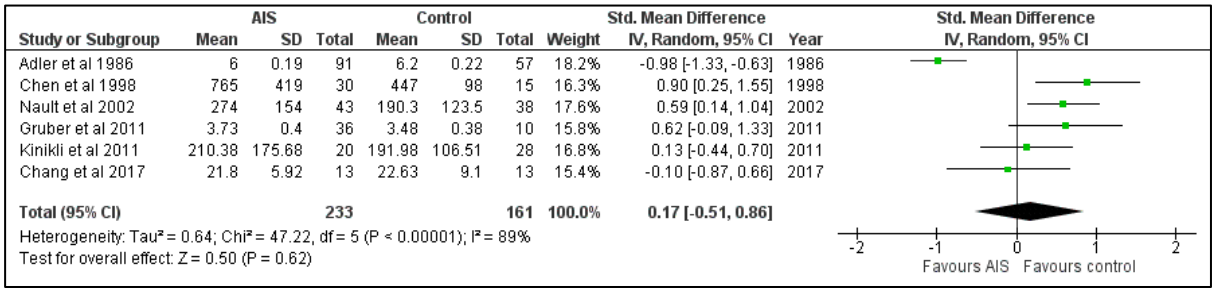
Due to the differences between studies, the results will be presented according to methodology type.

Static balance (standing) - 7 studies measured static balance in quiet standing with a force plate. Six studies measured overall centre-of-pressure (COP) sway area [28, 31-33, 37, 38] and four studies measured COP movement in the sagittal and lateral directions separately [31, 33, 37, 39]. Some studies measured these parameters with eyes open and/or eyes closed (Table 3.3). Results were combined and meta-analysis performed for each parameter. Due to the differences in units and how measurements were calculated, standardised mean differences were used in the meta-analysis.

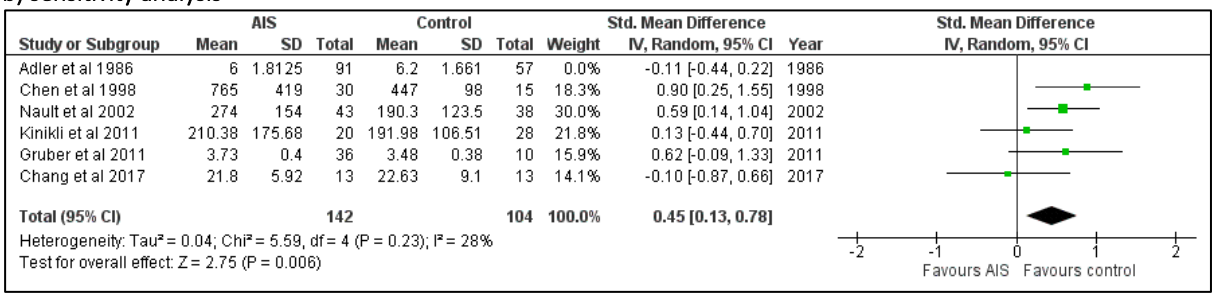
When all relevant studies were considered, the results of the meta-analysis for sway area (eyes open) indicated no difference in quiet standing balance between AIS and control participants (SMD 0.17, 95% CI -0.51 to 0.86, p=0.62, I^2=89%) (Figure 3.2a). Due to considerable heterogeneity, a sensitivity analysis was performed with the study by Adler et al [28] removed (Figure 3.2b). The new analysis indicated that sway area (eyes open) was greater on average for AIS participants, a sign of poorer balance (SMD 0.45, 95% CI 0.13 to 0.78, p=0.006, I^2 =28%).

Figure 3.2 Forest plot for static balance (standing) - sway area eyes open

a) all studies



b) sensitivity analysis

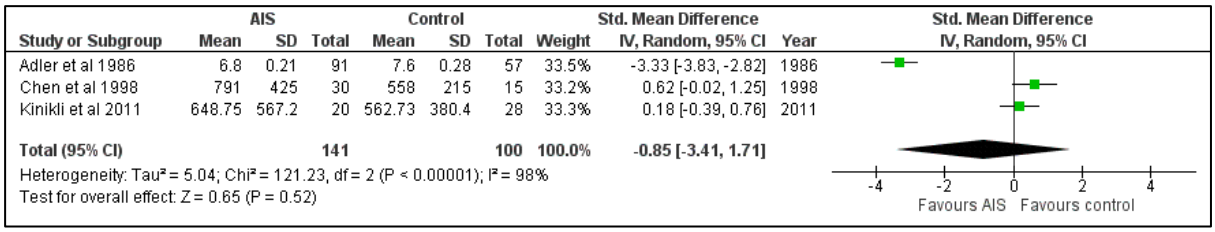


Only three studies measured sway area with the eyes closed (Figure 3.3a). The results for the meta-analysis suggest no difference between AIS and control participants (SMD -0.85, 95% CI -3.41 to 1.71, p=0.52, I^2=98%). As with eyes open, a considerable degree of heterogeneity was reduced by removing the study by Adler et al [28]. However, the overall conclusion of no between-group differences remained the same (SMD 0.38, 95% CI -0.05 to 0.81, p=0.08, I^2=0%) (Figure 3.3b).

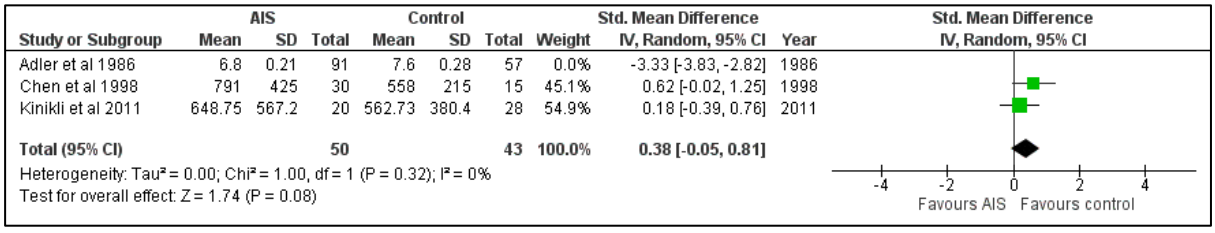
The study by Adler et al [28] measured sway area by calculating a dispersion co-efficient, reported to reflect the movement of the COP from a central point of origin. This was in contrast to other studies that, in general, measured the area of COP movement directly, and may account for the heterogeneity between their results and the remaining studies.

Figure 3.3 Forest plot for static balance (standing) - sway area eyes closed

a) all studies



b) sensitivity analysis

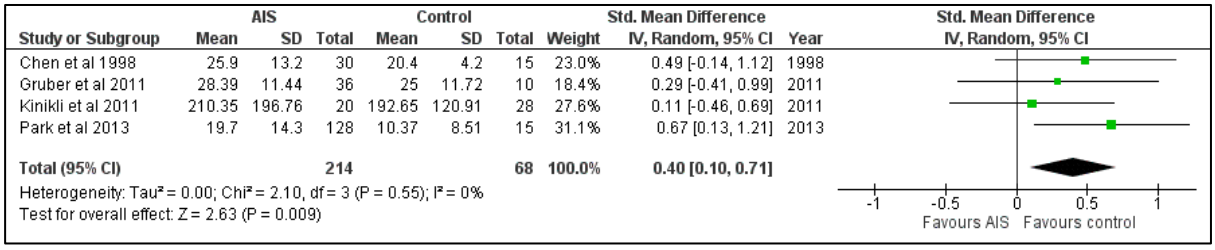


The amount of COP movement in the sagittal plane (anterior-posterior) during quiet standing with eyes open was measured by four studies. The meta-analysis of the combined results indicates that on average, the COP of AIS participants moved to a greater extent in the sagittal plane, suggesting poorer balance (SMD 0.40, 95% CI 0.10 to 0.71, p=0.009, I^2=0) (Figure 3.4a).

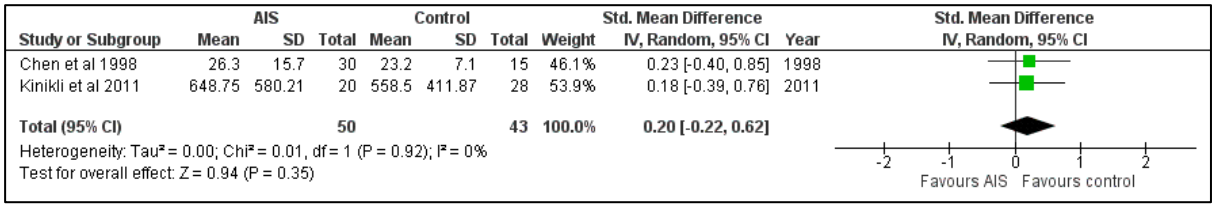
Only two studies measured the same parameter with eyes closed (Figure 3.4b). The results of the meta-analysis indicate no difference in sagittal COP movement between AIS and control participants (SMD 0.20, 95% CI -0.22 to 0.62, p=0.35, I^2=0).

Figure 3.4 Forest plot for static balance (standing) - sagittal movement

a) eyes open



b) eyes closed

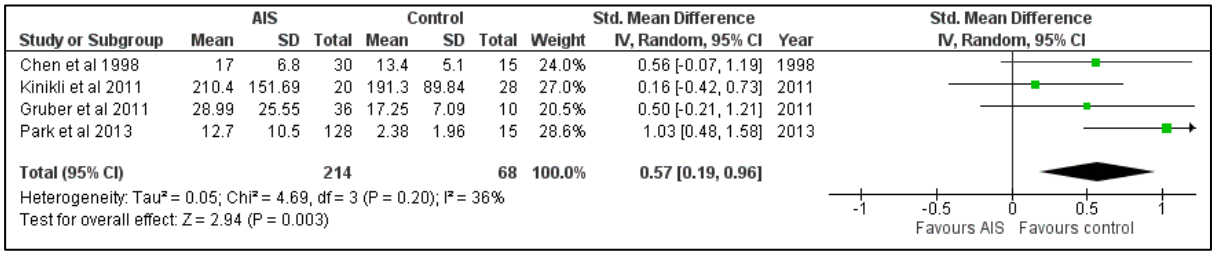


The same studies measured COP movement during quiet standing in the lateral direction. With eyes open, combined results indicate that the COP moves laterally to a greater extent in AIS participants than control participants, suggesting poorer balance (SMD 0.57, 95% CI 0.19 to 0.96, p=0.003, I^2=36%). Removing the results of either Park et al [39] or Kinikli et al [37] in sensitivity analyses reduced the heterogeneity to zero but did not alter the overall findings of greater lateral movement in the AIS group. Therefore, the forest plot with all studies retained is displayed (Figure 3.5a).

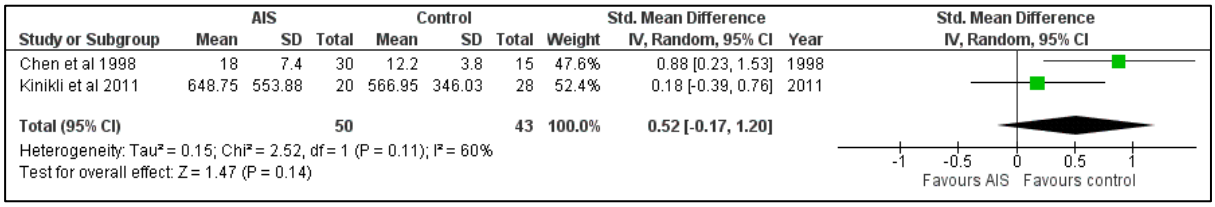
With eyes closed, meta-analysis of the combined results from three studies indicates that there was no difference between AIS and control participants in lateral COP movement (Figure 3.5b). Again, substantial heterogeneity between studies was apparent.

Figure 3.5 Forest plot for static balance (standing) - lateral movement

a) eyes open



b) eyes closed



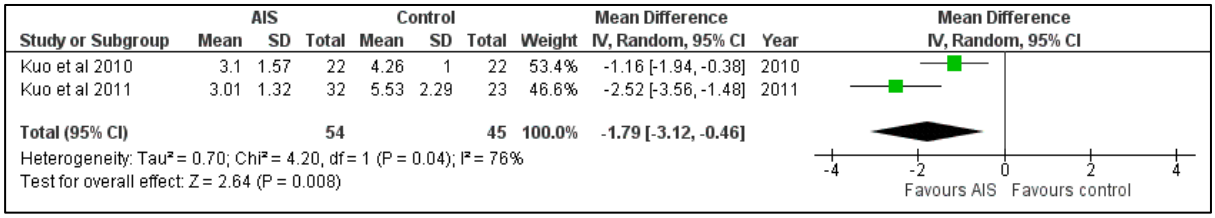
Static balance (sitting) - Only one study examined static balance in sitting to isolate trunk postural sway from whole body sway as tested in standing [29]. The study included 14 AIS and 12 control participants. The results (normalised to account for height) suggested that overall trunk movement (as measured by trunk sway, and sagittal and lateral COP movement) was less on average for AIS participants than for control participants, indicating better trunk stability in the AIS group (Table 3.3).

Dynamic balance (standing) - Two studies evaluated dynamic standing balance by asking participants to maintain quiet standing on an unstable platform [34, 35]. One study tested this under three conditions: eyes open, eyes closed or while standing on a sponge balance pad [34], while the other used eyes open only [35]. Rather than recording COP, the tilting angle of the platform was measured in sagittal and lateral directions. As well as these parameters, one study used this information to calculate a balance index [34]. High balance index scores reflect greater movement and therefore poorer balance.

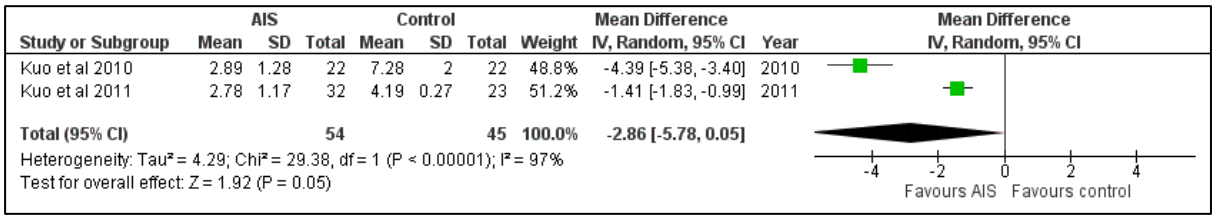
The results of two studies for tilt angles in the eyes open condition were combined for meta-analysis and are illustrated in Figure 3.6a and b. These suggest that sagittal tilt angles were lower for AIS participants than controls, and that these differences were statistically significant (MD -1.79, 95% CI -3.12 to -0.46, p=0.008, I^2=76%). For lateral tilt angles, no statistically significant difference was seen between the two groups (MD -2.86, 95% CI -5.78 to 0.05, p=0.05, I^2=97%). Again of note is the considerable heterogeneity between the two studies despite using similar methodologies.

Figure 3.6 Forest plot for dynamic balance - eyes open

a) sagittal tilt



b) lateral tilt



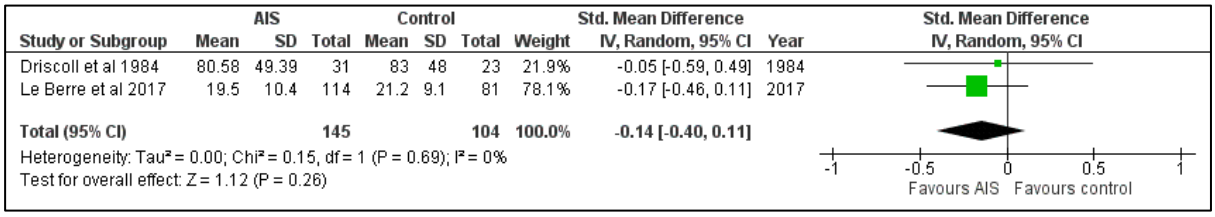
The results from one study [34] for eyes closed and sponge pad conditions (Table 3.3) indicate that on average tilt angles were lower in both directions for AIS participants compared to controls, and these differences were statistically significant. Differences between AIS and control participants for the derived balance index reflected the results for tilt angles with AIS participants demonstrating statistically significant lower index scores (i.e. better balance) than controls for eyes closed and sponge pad conditions, although not for eyes open condition. Overall, these results suggest that AIS participants had better dynamic standing balance than control participants.

One leg static standing balance - one leg standing balance ability was evaluated in two studies. Driscoll et al [30] timed participants in the test position (eyes closed) for a maximum of 30

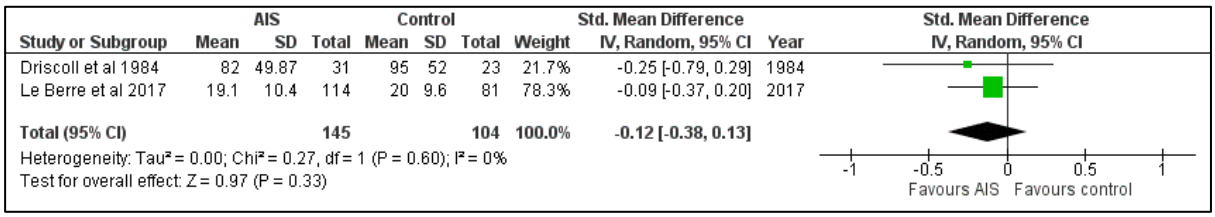
seconds as they performed 5 trials for each leg. The results of each trial for each leg were summed to give a maximum possible score of 150 seconds for each leg. A similar procedure was used by Le Berre et al [41] although only 1-2 trials were conducted for each leg, and the longest time for each trial was recorded. Results were combined and meta-analyses were performed for each leg separately and for both legs combined (Figure 3.7a, b, c). Due to the differences in calculating stance time, standardised mean differences were used. The forest plots indicate that there was no difference in 1 leg static standing balance ability between AIS and control participants (combined leg SMD -0.13, 95% CI -0.39 to 0.12, p=0.30, I^2=0%).

Figure 3.7 Forest plot for 1 leg standing balance

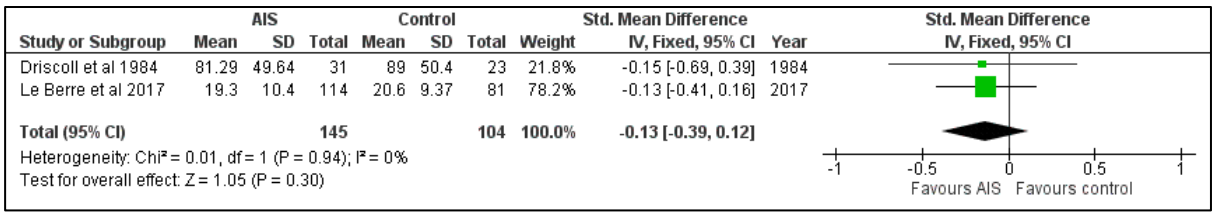
a) Left leg



b) Right leg



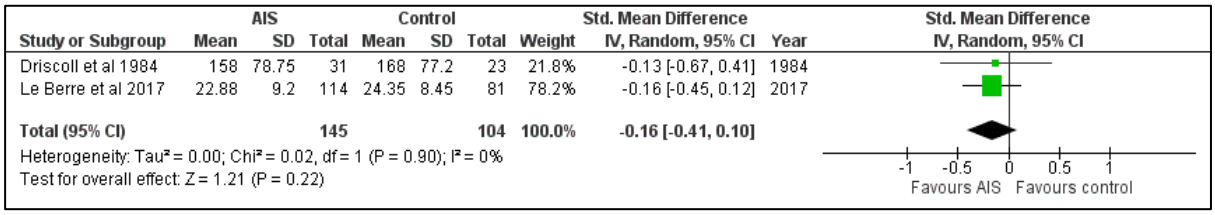
c) combined



Tandem stance (Sharpened Romberg test) - the same two studies timed balance ability during tandem standing. Driscoll et al [30] asked participants to perform 4 trials for a maximum of 60 seconds each. The time for each trial was summed to give a maximum possible time of 240 seconds. Le Berre at al [41] only used 1-2 trials for each leg up to a maximum of 30 seconds.

Results were recorded for the longest trial. For the purpose of this analysis, results for left-foot forward and right-foot forward were combined (Figure 3.8). Standardised mean differences were used due to differences in measuring procedures. The result of the meta-analysis of combined results indicates that on average there was no difference in tandem standing balance ability between AIS and control participants (SMD -0.16, 95% CI -0.41 to 0.10, p=0.22, I^2=0%).

Figure 3.8 Forest plot for tandem standing balance - combined



Destabilisation testing - two studies examined participant balance response to perturbation or destabilisation. Bruyneel et al [40] asked participants to maintain seated balance after destabilisation in an anterio-posterior direction. Ground reaction forces in the sagittal and lateral directions were measured with a force plate mounted underneath the seating device and the total force used in each direction to maintain stability after destabilisation were calculated. The test was performed with eyes open and eyes closed. The results (Table 3.3) indicate that AIS participants generated greater forces in both directions to maintain stability than control participants across all conditions and in both directions, and these differences were statistically significant. The authors concluded that it required more effort for AIS participants to maintain balance when challenged.

In a second study, Kuo et al [35] evaluated participants' response to backward perturbation in standing. Participants stood on a moveable platform and the platform was destabilised in the posterior direction. Lateral and sagittal tilt angles of the platform were recorded. The authors reported that the platform tilt angles following perturbation were on average less in both directions for AIS participants than those for the control participants, indicating greater stability, and that these differences were statistically significant (Table 3.3).

Other - in one study, static and dynamic standing balance was evaluated under reduced or conflicting sensory conditions [36]. Six different visual and support surface conditions involving eyes open and closed, stable or 'sway-referenced' (i.e. moved in same direction and magnitude as subjects' body sway) platform, and static or moving visual background were scored from 0-100 (Table 3.3). By combining scores from certain conditions, somatosensory, visual and vestibular ratios were calculated. The somatosensory ratio quantified differences in balance scores between eyes open and eyes closed on a fixed platform (i.e. reliant on somatosensory information to maintain balance); the visual ratio quantified differences in balance scores between a fixed and a sway-referenced moving support surface (i.e. reliant on visual information); the vestibular ratio quantified the differences in balance scores between eyes open on fixed surface and eyes closed on a sway-referenced moving platform (i.e. reliant predominantly on vestibular information). The authors reported that there were no statistically significant differences between AIS and control participants for any of the calculated balance ratios.

(iv) Summary

Despite the large number of studies that have investigated balance in people with AIS compared to people without AIS, the results to date are inconclusive. The studies included in this review have evaluated different aspects of balance with contrasting results. Attempts to combine results in meta-analyses have allowed some comparisons between studies to be made but a lack of consistency in testing methodologies and parameters measured has limited their effectiveness. In summary:

- Seven studies of static standing balance provided some evidence of poorer balance amongst AIS participants compared to controls for all sway parameters measured when the eyes were open, but not with eyes closed.
- One small study of static sitting balance reported better balance amongst AIS participants.
- Two studies of dynamic standing balance reported better performance by AIS participants for 3 out of 4 tested conditions.

- Two studies of 1 leg and tandem standing balance reported no difference between groups.
- Two studies of balance response following destabilisation produced contrasting results with one study reporting worse performance by AIS participants and the other reporting the reverse.

There appears to be some evidence to suggest that people with AIS have poorer static standing balance than people without AIS, although this only seems to apply when eyes are open rather than eyes closed. This may be because the smaller number of studies and participants involved in evaluating eyes closed compared to eyes open resulted in insufficient power to detect any differences.

Apart from static standing balance, most outcomes were only evaluated by one or two studies. The majority of included studies involved small sample sizes and less than half made any attempts to match AIS and control participants. All studies were also at uncertain risk of bias for most key domains and there was often considerable heterogeneity between studies. Until these issues are addressed, and greater consistency in outcome measures and testing procedures is achieved, the question of differences in balance between people with AIS and people without AIS will remain unanswered. Further research of this nature is therefore likely to have an important effect on the current evidence base and may change this evaluation.

3.2.3 Proprioception

Five studies were identified that evaluated proprioception in AIS and control participants. Three of these were excluded: Yekutiel et al [42] did not report sufficient data to make a true comparison between participant groups; both Cook et al [43] and Keessen et al [44] included participants that had undergone spinal correction surgery and, in the former study, the control group was on average 4 years older than the AIS group, both factors which could have affected the results.

(i) Characteristics of included studies

Summaries of the included studies are provided in Table 3.4. Studies were conducted in the USA [45] and France [46] with sample sizes ranging from 17 [45] to 30 [46] AIS and 12 [45] to

14 [46] control participants. The age of the participants was similar between studies (mean AIS group: 14.8yrs and 15.5yrs; mean control group: unknown and 14.6yrs). Barrack et al [45] did not provide details of the control group although they did state that they matched cases and controls by age. Details of the ratio of female:male participants was poorly reported by both studies with information only provided for the AIS group in Barrack et al [45] and for neither group in Guyot et al [46].

Amongst AIS participants, the mean Cobb angle was similar between the studies ranging between 26.8 and 24.8 degrees. Guyot et al [46] included participants with a range of curve types (i.e. thoracic, thoracolumbar, lumbar and double curves) and in both directions (left and right) in varying proportions. In contrast, Barrack et al [45] only included participants with right-sided thoracic curves. Guyot et al [46] did not describe whether any of the AIS participants had undergone treatment, whereas some of the participants in Barrack et al [45] had received surgery or bracing. During sub-group analysis of the results, Barrack et al [45] reported that there were no differences in results between AIS participants by treatment group, information that was not provided by Cook et al [43] and Keessen et al [44] and therefore caused their exclusion from the review.

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.11. In general, as with many older studies, lack of reporting of key details by Barrack et al [45] resulted in uncertainty as to how at risk the study was across all types of potential bias. The study by Guyot et al [46] was reported to a higher standard and was judged at low risk of classification bias. However, a lack of information regarding control participants and whether assessors were blinded led to the study being at uncertain risk of selection and measurement bias and at high risk of reporting bias.

(iii) Results

The two included studies investigated the ability of participants to reproduce joint angles either in the knee [45] or the neck [46] (Table 3.4]. This involved the joint being moved (passively or actively) to a specified angle(s) and then returned to the start position. The participant then had to move their knee or neck and attempt to reproduce the initial position. Discrepancies (error) between the initial and estimated position were recorded in degrees.

Barrack et al [45] also examined the threshold for detection of movement in the knee which involved participants having to indicate when they first noticed the knee being passively moved.

Joint angle reproduction - due to the different body parts tested and differences in testing methodology, the results of these two studies were summarised as part of a narrative analysis. Barrack et al [45] reported a statistically significant difference in mean error between groups with AIS participants recording almost double the amount of error on average than control participants across both limbs (AIS: mean 5.1 degrees, SD 2.5; control: mean 2.7 degrees, SD 1.5; MD 2.4 degrees, 95% CI 0.74 to 4.06, p=0.006). In contrast, in the neck, there was no statistically significant difference between groups when both movement directions were combined (MD 0.22 degrees, 95% CI -0.77 to 1.21, p=0.66). Guyot et al [46] further reported that 40% (12/30) of AIS participants had average errors in neck reproduction ability of more than 4.5 degrees, which they defined as pathological. No difference in curve severity or age was found between AIS participants with 'pathological' and 'non-pathological' error. Post-hoc sub-group analyses revealed statistically significant differences between groups of AIS1 ('pathological'), and AIS2 ('non-pathological') and control participants (AIS1: mean 4.6 degrees, SD 1.2; AIS2: mean 2.8 degrees, SD 0.7; controls: mean 3.3 degrees, SD 1.7 respectively). Unfortunately, no information was provided regarding whether any control participants recorded errors greater than 4.5 degrees, therefore it is difficult to know if this sub-group analysis is valid. Even with this subgrouping, the mean differences in error between groups reported in both studies was small (1.3 to 2.4 degrees) which calls into question how much of a practical difference there would be between people with and without AIS.

Movement detection threshold - Barrack et al [45] also evaluated differences in the threshold of movement detection of the knee with AIS participants on average recording thresholds almost double (i.e. less sensitive) those of control participants (AIS: 2.6 degrees, SD 1.8; control: 1.4 degrees, SD 0.6; MD 1.2 degrees, 95% CI 0.09 to 2.31, p=0.04). With no other studies measuring this variable, it is difficult to make any definitive conclusions regarding movement detection ability in people with AIS.

(iv) Summary

From the limited amount of evidence available, the joint angle reproduction ability of people with AIS appears to be reduced by a small amount in the knee but not in the neck compared to people without AIS. The ability to detect knee movement also appears to be reduced in AIS participants. These findings are based on only two studies with small sample sizes, uncertain to high risk of bias across key domains, and with contrasting results, therefore no final judgement can as yet be made as to whether people with AIS have reduced proprioceptive function. Further research is likely to have an important impact on currently available evidence and may change this evaluation.

3.2.4 Vibration threshold

Following reports of altered proprioception in AIS, numerous studies have attempted to evaluate functioning of the posterior column of the spinal cord as proprioceptive information is conducted primarily through these pathways [47]. Testing of vibratory threshold is one method used to evaluate posterior column function [48]. Testing involves applying a vibration stimulus to a bony prominence and slowly increasing the magnitude of vibration until the stimulus is perceived. The lower the threshold, the greater the ability to detect vibration.

Four studies were evaluated for testing of the vibration threshold in AIS and control participants. One of these was excluded as participants in both groups were not adolescents (mean age > 30 years old) and a third of AIS participants had undergone spinal correction surgery [24].

(i) Characteristics of included studies

Summaries of the included studies are provided in Table 3.5. Studies were conducted in the USA [47, 48] and Canada [49] with sample sizes ranging from 14 to 58 AIS and 20 to 57 control participants. The age of the participants was similar between studies (mean AIS group: 14.4yrs to 15.4yrs; mean control group: 13.6yrs and 14.5yrs). All participants were female which reflects the higher incidence of AIS amongst the female population. Only one study described matching of AIS and control participants, in this case by age and sex [47].

Amongst AIS participants, the mean Cobb angle was similar between the studies ranging between 30 and 35 degrees. Two studies [48, 49] included participants with a range of curve

types, predominantly to the right. Barrack et al [47] did not give details as to curve type. None of the studies provided details as to current or previous treatment of AIS participants.

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.11. In general, all included studies were judged to be at uncertain risk of bias due to lack of reporting of key domains. Uncertainty was particularly evident in relation to the areas of selection and reporting bias due to insufficient information participants (e.g treatment details, recruitment source, inclusion criteria) and lack of reporting of any potential confounders. Barrack et al [47] was judged to be at low risk of measurement bias, McInnes et al [49] was judged at low risk of classification and measurement bias and Wyatt et al [48] was at uncertain risk of bias for all domains.

(iii) Results

The three included studies measured vibration thresholds at a number of body locations: ulnar styloid (n=2), great toe (n=2), 1st metatarsal-phalangeal joint (MTP) (n=3) and medial malleolus (n=1) (Table 3.5). As the testing methodology was similar for all three studies, results were combined and a meta-analysis conducted for testing of the ulnar styloid, great toe and 1st MTP. An overall meta-analysis was also performed by combining the results of each location.

Ulnar styloid and great toe - Forest plots for the two studies that evaluated vibration threshold at the ulnar styloid and great toe [47, 48] are shown in Figure 3.9a and b. These indicate that AIS participants had lower thresholds (i.e. more sensitive) to detect vibration than control participants (ulnar styloid: MD 0.08, 95% CI -.014 to -0.02, n=146; great toe: MD -0.12, 95% CI -0.18 to -0.05, n=146). However, these findings should be interpreted with caution due to the considerable statistical heterogeneity as revealed by the χ^2 and I^2 values.

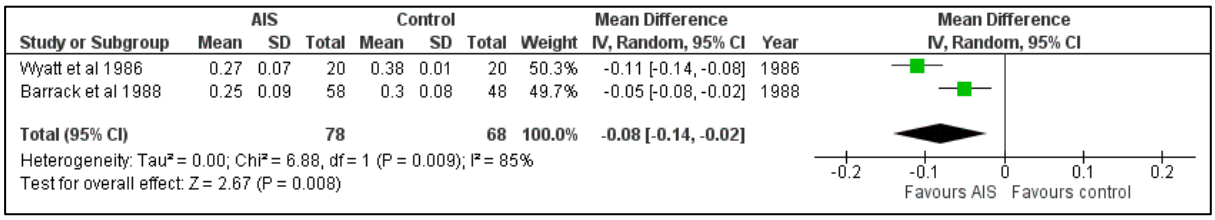
1st MTP - Forest plots for the three studies that evaluated vibration threshold at the 1st MTP [47-49] are shown in Figure 3.9c. The results for Wyatt et al and Barrack et al [47, 48] favoured lower thresholds in AIS participants whereas McInnes et al [49] reported the reverse. Overall, these suggest that there is no difference in vibration detection thresholds between AIS participants and controls (MD: -0.08, 95% CI -0.19 to 0.02, n=182). Due to the contrasting results and considerable heterogeneity, a further analysis was performed without McInnes et

al [49] (Figure 3.9d). Although this indicated that AIS participants had lower vibration detection thresholds than controls (MD -0.12, 95% CI -0.19 to -0.05, n=146), consistent with the results for the ulnar styloid and great toe, the level of heterogeneity remained considerable and therefore, results should be interpreted with caution.

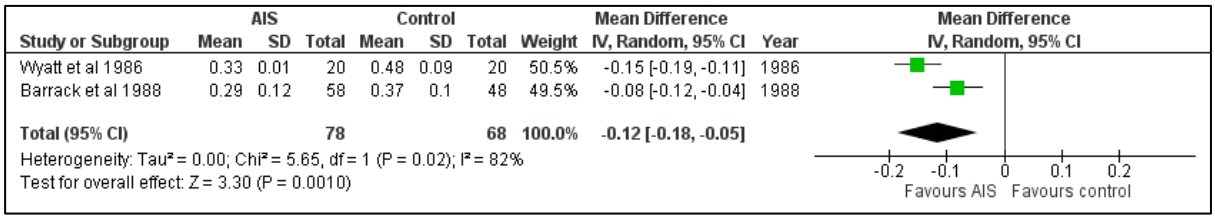
Overall - Combining results for each location (including medial malleolus) allowed an analysis of overall vibration detection ability (Figure 3.9e). The results of this were similar to those for the 1st MTP, with the results of Wyatt et al [48] and Barrack et al [47] in conflict with McInnes et al [49], suggesting that there was no difference between the groups (MD -0.06, 95% CI -0.18 to 0.06, n=182). A further sensitivity analysis was performed by removing the results of McInnes et al (Figure 3.9f). The results of this indicated that AIS participants had a lower vibration detection threshold than control participants (MD: -0.10, 95% CI -0.15 to -0.04, n=146). These results can be interpreted with greater confidence due to the lower levels of heterogeneity (I^2=30%) indicating greater consistency between the studies.

Figure 3.9 Forest plots of vibration threshold

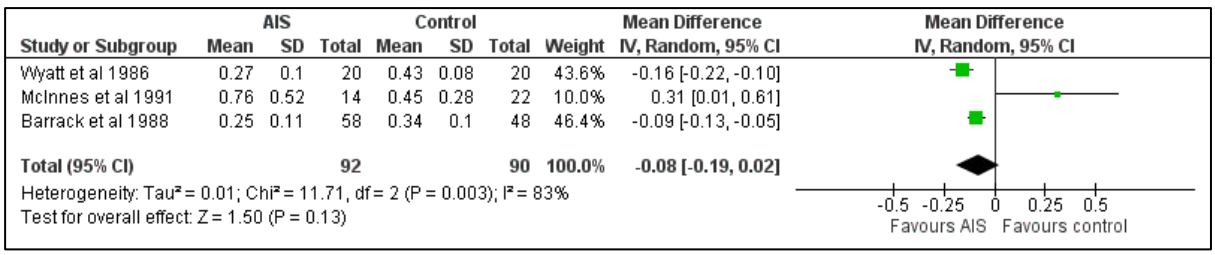
a) ulnar styloid



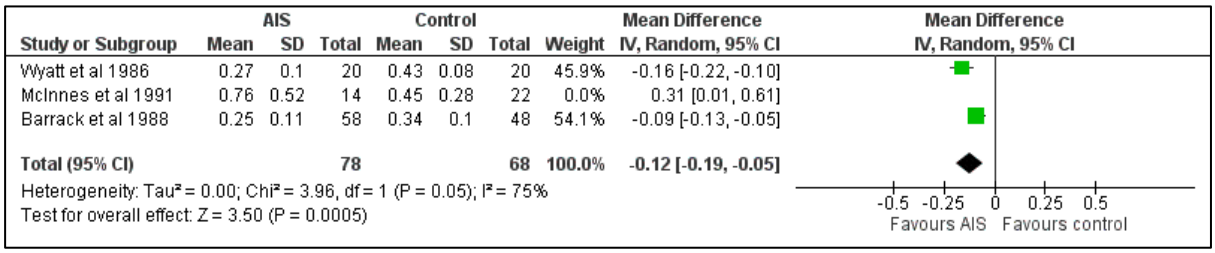
b) great toe



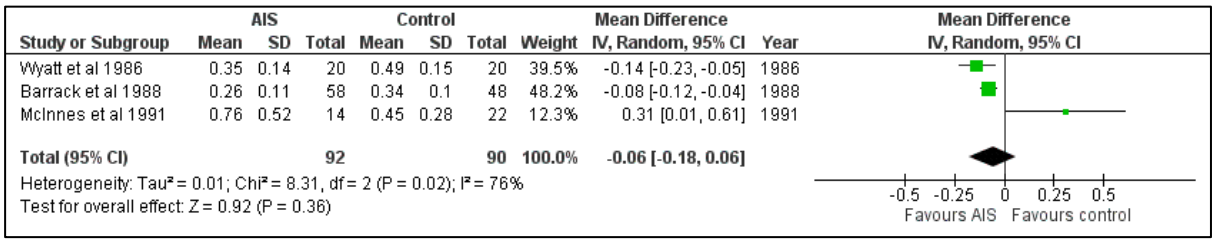
c) 1st MTP



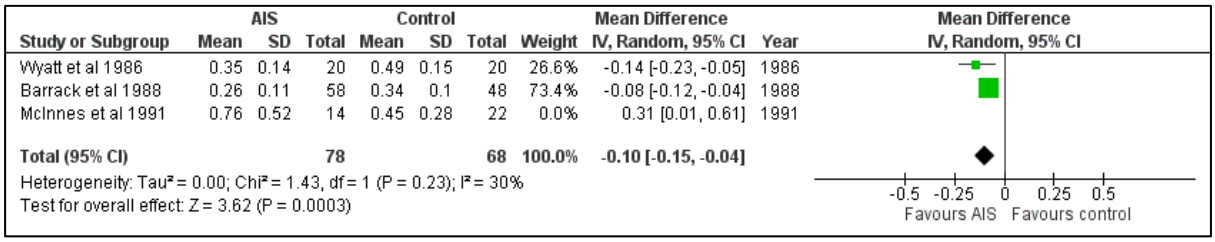
d) 1st MTP less McInnes et al



e) overall



f) overall less McInnes et al



(iv) Summary

Meta-analysis of the evidence from the three included studies indicates that vibration detection ability is increased in people with AIS by a small amount compared to people without AIS. These findings need to be interpreted with caution due to the conflicting results between the studies, the uncertain risk of bias across key domains, small sample sizes, and the considerable heterogeneity reported in the meta-analyses, apart from the sensitivity analysis of overall results. It is also not clear whether the magnitude of differences seen is sufficient to result in changes of functional significance. Further research is likely to have an important impact on currently available evidence and may change this evaluation.

3.2.5 Perception of vertical

Alterations in spatial orientation have been proposed as a possible factor in AIS, with flow on effects resulting in altered spinal muscle activation. One method of assessing spatial orientation is to examine the ability to judge vertical alignment.

Five studies investigated the ability to judge vertical alignment in participants with AIS compared to control participants. Two of these were excluded due to insufficient reporting of data which prevented an accurate comparison between groups [50, 51].

(i) Characteristics of included studies

A summary of the three included studies is provided in Table 3.6. Studies were conducted in the Czech Republic [52], Taiwan [32] and France [53] with sample sizes ranging from 13 to 30 for both AIS and control participants. The age of the participants was similar between studies with mean ages ranging from 13.9yrs to 15.7yrs. One study included only female participants [53], whereas the proportion of females in the other studies ranged from 69% to 78%. All three studies described matching of AIS and control participants by at least age with Cakrt et al [52] also matching by sex and Le Berre et al [53] by BMI, handedness and stage of puberty (Tanner stage).

All studies included AIS participants with a wide range of curve severity. Two studies [32, 52] included participants with curves up to 30 to 40 degrees, while one study [53] included curves sizes up to 74 degrees. One study [53] only included AIS participants with right thoracic curves whereas [32, 52] included a range of curve types in both directions. One study [53] provided no details as to current or previous treatment of AIS participants. Two studies [32, 52] stated that participants had not undergone spinal correction surgery or active treatment respectively.

Each of the studies used different methodologies to assess participants' ability to perceive verticality. Cakrt et al [52] asked participants to judge the verticality of a line drawn on the inside of a rotating drum. Chang et al [32] used a modified rod-and-frame test where participants had to assess the verticality of a line visualised on a computer screen. Le Berre et al [53] asked participants to move a line projected onto a wall until it was vertical using a joystick. In a separate experiment, they also asked blindfolded participants to judge the verticality of their body whilst seated in a rotating drum-like apparatus.

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.11. Two studies were judged overall to be at uncertain risk of bias and one study at high risk of bias. Two studies were at low risk of selection bias [32, 52], two studies were at low risk of classification bias [52, 53], and one study was deemed to be at high risk of bias due to lack of assessor blinding [52]. The remaining domains of each study were judged to be of uncertain risk of bias due to lack of information.

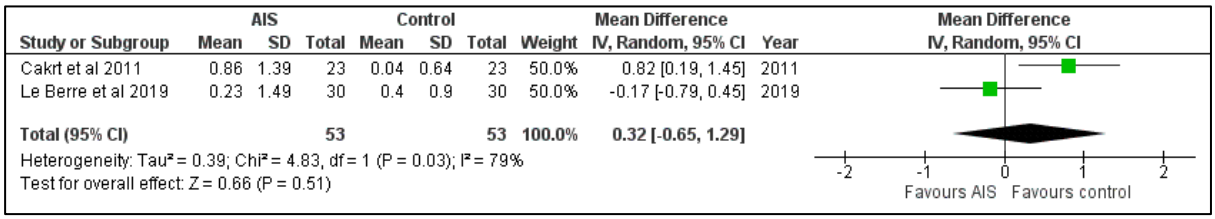
(iii) Results

Subjective visual vertical (SVV) - Participants in the study by Chang et al [32] were asked to judge whether lines presented on a computer screen were vertical by answering yes on no via a computer keyboard (Table 3.6). Reaction times in making correct decisions were also recorded. They reported that there was no difference in either accuracy or reaction time between AIS and control participants (correct response: MD 2%, 95% CI -9.3 to 13.3, p=0.72; mean reaction time: MD 24.3 ms, 95% CI -86.7 to 135.4, p=0.66).

The other two studies measured the difference (i.e. error) between actual and estimated vertical lines using a variety of methodologies [52, 53]. Therefore, the results of these were combined in a meta-analysis (Figure 3.10) using absolute error values. The forest plot reveals the contrasting results of the two studies and suggests that there is no difference between people with and without AIS (MD 0.32 degrees, 95% CI -0.65 to 1.29, n=106). It should be noted that considerable heterogeneity exists, possibly due to the differences in testing methodologies, and therefore these results should be interpreted with caution.

Le Berre et al [53] also reported on SVV with a rotating pattern in the background to the projected line which was not included in the meta-analysis. The results indicate that both groups were more accurate under this condition but with no statistically significant difference between AIS participants and control participants (MD 0.12 degrees, 95% CI -1.74 to 1.98, p=0.898).

Figure 3.10 Forest plot subjective visual vertical



Subjective postural vertical (SPV) - as well as visual estimates of verticality, one study [53] also asked participants to estimate whether their body was in vertical alignment whilst blindfolded and seated in a rotating drum-like apparatus. In contrast to their results for SVV, they reported that AIS participants were less accurate than control participants in their estimates of actual vertical (MD 2.05, 95% CI 1.09 to 3.01, p=0.001).

(iv) Summary

The results of the three included studies suggest that there is no difference in perception of vertical in people with AIS compared to people without AIS, at least as far as testing of SVV is concerned. There is some evidence to suggest that people with AIS were less accurate when they were asked to judge body alignment without visual information compared to people without AIS. All of these studies were at uncertain to high risk of bias, involved small sample sizes, and had conflicting results. Each study also used different testing methodologies and combining results from two of the studies resulted in considerable heterogeneity. Therefore, it is likely that further research will have an important impact and may change this evaluation.

3.2.6 Vestibular testing

A number of studies have utilised different methods to assess vestibular function in AIS. These included testing of the semicircular canals, vestibular-ocular reflex and the otolith system. These will be reviewed separately in the following sections.

3.2.6.1 Semicircular canal testing

Six studies were identified that evaluated the effects of direct stimulation of the semicircular canals (SCC). Four studies were excluded: three studies used an inappropriate control group (a cohort from >10 years previously) [22, 23, 54]; one study did not provide sufficient data to allow an accurate comparison between groups [55].

(i) Characteristics of included studies

Summaries of the included studies are provided in Table 3.7. The two included studies were conducted in the USA [56] and France [57]. Sample sizes ranged from 17 to 18 AIS and 9 to 25 control participants. One study reported mean ages of the participants of 15.5yrs and 16.7 yrs (AIS and control groups respectively) [57], whereas the other study reported age-matched participants between 11-15yrs [56]. One study only included female participants [56]. The other study reported the proportion of female participants as between 67 to 76% in the AIS and control group respectively [57].

Amongst AIS participants, Jensen et al [56] reported Cobb angle of between 5-45 degrees with curves in both directions (predominantly right side) and across all locations. In the study by Hitier et al [57], Cobb angles ranged from 15-40 degrees (mean 26.7 degrees, SD 8.3). No information was provided regarding previous treatment in one study [56]; the other study stated that AIS participants had not received any treatment [57].

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.12. All included studies were deemed to be at uncertain risk of bias overall. Jensen et al [56] was at low risk of classification bias, and uncertain risk of selection, measurement and reporting bias. Hitier et al [57] was at low risk of classification bias and uncertain risk across other domains.

(iii) Results

The two included studies used different methods of SCC stimulation (Table 3.7). Different properties of the resulting nystagmus were evaluated, therefore they will be considered separately.

Jensen et al [56] used the Southern Californian postrotatory nystagmus test (SCPNT) which involved inducing nystagmus by rotating the participant whilst seated. Nystagmus duration time was measured as well as categorisation of excursion distance and rhythm into normal and abnormal responses. They reported statistically significant differences between AIS and control participants in nystagmus duration for mean clockwise, counter-clockwise and the sum of combined (clockwise and counter-clockwise) rotation, with shorter duration in AIS participants compared to controls (Table 3.7). Statistical analysis of between-group differences in

nystagmus excursion and rhythm were not provided but was performed for the purposes of this review. The results indicated that there were no differences in the frequency of normal or abnormal responses for either excursion or rhythm (for combined, clockwise or counterclockwise rotation) between AIS and control participants (excursion combined: χ^2=2.66, p=0.10; rhythm combined: χ^2=1.84, p=0.18).

Hitier et al [57] measured mean eye speed, directional preponderance and the canal paresis index (i.e. right versus left SCC) using electro-nystagmography following caloric stimulation of the SCC. In essence, this involves inducing nystagmus by pouring water into the inner ear and measuring the resulting eye movement induced by the reflex response. They reported no difference between AIS and control participants for any functional measures (Table 3.7).

3.2.6.2 Vestibular-ocular reflex testing

Three studies were identified that evaluated the effects of vestibular-ocular reflex (VOR) testing. One study was excluded due to insufficient information for between-group comparisons and an inappropriate control group (age range AIS: 8-16yrs; controls: all 12yrs) [58].

(i) Characteristics of included studies

Summaries of the included studies are provided in Table 3.7. The two included studies were conducted in Canada [59, 60] with sample sizes ranging from 10 to 36 AIS and 13 to 16 control participants. Both studies reported similar mean ages of participants of between 14.6yrs to 17.4yrs with one study reporting age-matching of AIS and control participants [59]. The proportion of female participants was also similar in the two studies ranging from 78% to 90%.

Simoneau et al [59] reported that Cobb angle amongst AIS participants ranged from 28-51 degrees, all of which were right thoracic curves. AIS participants in the other study [60] had a mean Cobb angle of 27.9 degrees but no details were provided as to direction or location. None of the participants in one study had received any treatment [59] whereas in the other study, 21 had undergone bracing and a further 6 had received other conservative treatments, although the exact nature of these was not specified [60].

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.12. Both studies were overall at uncertain risk of bias with poor reporting resulting in a lack of information particularly with regard to the key domains of selection and classification bias.

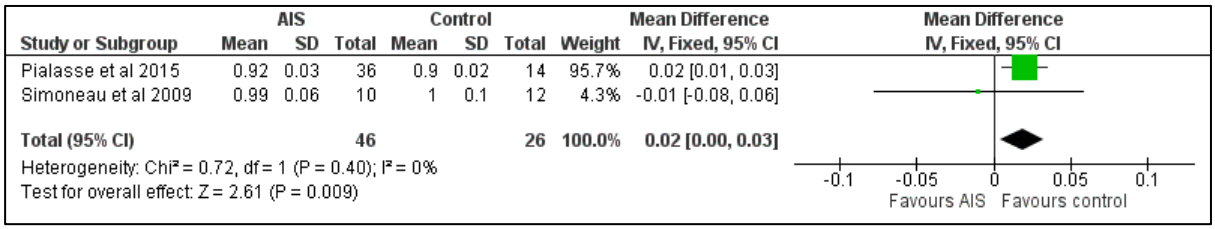
(iii) Results

Both studies calculated VOR gain following rotational tasks in which eye movements were recorded using electro-oculography. Due to the similarities in testing procedures and measured parameters, results were combined in a meta-analysis.

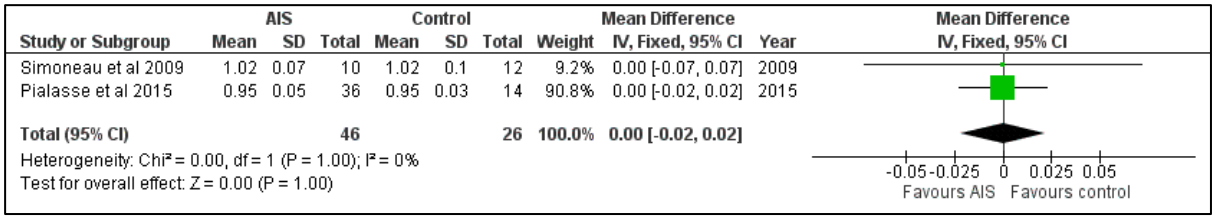
Forest plots for the two included studies that measured VOR gain for left, right and combined directions are illustrated in Figure 3.11a, b and c. These indicate that there was no overall difference between AIS and control participants (MD 0.01, 95% CI -0.01 to 0.03), nor for the right rotation task (MD 0.0, 95% CI -0.02 to 0.02). A small but statistically significant difference was observed between AIS and control participants for the left rotation task (MD 0.02, 95% CI 0.0 to 0.03) although the lower boundary of the 95% CI was almost equivalent to zero (i.e. no effect).

Figure 3.11 Forest plots of VOR gain

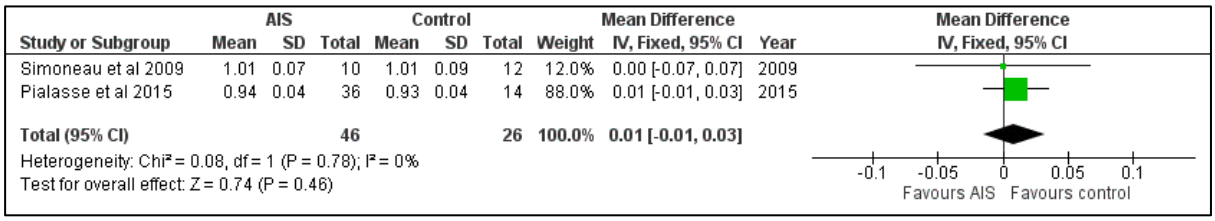
a) Left



b) Right



c) Combined directions



3.2.6.3 Otolith testing

Two studies were identified that tested otolith function in AIS and control participants. Otolith function was evaluated as it has an important role in regulating postural control of the spine, therefore potentially being involved in the development of AIS.

(ii) Characteristics of studies

One study was conducted in France [61] and the second study in Israel [62]. They included similar numbers of participants in each group (AIS n=29 and 30; controls n=12 and 19). The mean age of participants was similar between studies although the range was different both within- and between studies. One study reported participant ages of 6.5 to 15yrs and 11-15yrs for AIS and control groups respectively [61], while the other study reported AIS participants ranging from 9-23yrs [62]. No details were provided with controls for this study although they reported that control participants were age-matched with AIS participants. Similar proportions of female participants in each group were reported by one study (90% and 83% AIS and control groups respectively) [61]. In contrast, the other study reported a large difference with 86% and 47% female participants in AIS and control groups respectively [62].

Both studies included a wide range of curve severity with Cobb angles ranging from 10-85 degrees in one study [61] and 28-72 degrees in the other [62]. The mean Cobb angles indicate that AIS participants in Pollak et al [62] tended to have on average curves that would be classified as severe. Both studies included curves in both directions and in a variety of spinal regions, though no information was reported in either study regarding previous treatment.

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.12. Both studies were considered at high risk of selection bias due to disparities between their respective AIS

and control groups. Control participants in Wiener-Vacher et al [61] had a different age profile to AIS participants. In the study by Pollak et al [62], the proportion of female control participants was far lower than their corresponding AIS group. Wiener-Vacher et al was also at high risk of reporting bias due to failure to report the results of certain parameters. Both groups were at uncertain risk of bias for most other domains due to lack of reporting of key information.

(iii) Results

The two included studies used different methodologies for evaluating otolith function and measured different parameters (Table 3.7). Therefore, the results of these will be discussed separately.

Wiener-Vacher et al [61] evaluated asymmetry in otolith function using the off-vertical axis rotation (OVAR) test. Differences between both horizontal and vertical eye movement velocity obtained by clockwise and counterclockwise rotation were measured by electro-oculography, and directional preponderance was calculated for both horizontal and vertical components of eye direction. They reported a statistically significant difference between AIS and control participants for absolute horizontal directional preponderance (MD 0.68 degrees/sec, 95% CI 0.26 to 1.10, p=0.004) with AIS participants on average having a greater difference in horizontal eye movement velocity when rotated in one direction than the other. In contrast, they did not observe a statistically significant difference in directional preponderance for vertical eye movement velocity (MD 0.08, 95% CI -0.48 to 0.64). No association was reported between these results and the magnitude or direction of the spinal curve. The authors went on to state that AIS participants had a greater frequency of higher directional preponderance results although no statistical analysis was performed to determine if this difference was statistically significant.

Pollak et al [62] used cervical vestibular-evoked myogenic potential (VEMP) testing to evaluate otolith function. This procedure involves recording cervical muscle reflex activity following auditory stimulation, a process facilitated by the otolith system. Latencies of the first positive (P13) and negative (N23) wave were recorded along with amplitude, and an amplitude asymmetry ratio was calculated to evaluate side-to-side differences. The authors reported no between group differences in P13 latency or amplitude asymmetry ratios. A statistically

significant difference in mean N23 wave latency (MD 1.9 ms, 95% CI 0.43 to 3.37, p<0.05) and mean wave amplitude (MD 23.2 microV, 95% CI 1.75 to 44.65, p<0.05) was reported between AIS and control participants, with AIS participants recording longer latencies and larger amplitudes. No within group differences were observed for side-to-side differences for either group. The authors concluded that some between group differences were apparent indicating possible vestibular abnormalities in AIS participants.

3.2.6.4 Summary

The six studies of vestibular function included in this review have used a variety of methodologies. These have involved only two studies for each methodology type, been poorly reported and consequently of uncertain to high risk of bias. All of the six studies have involved very small sample sizes with only one study containing a group exceeding 30 participants [Pialasse et al].

To summarise:

- One study of rotatory stimulation of SCC reported reduced duration of nystagmus response in AIS participants compared to controls with no differences in other measured parameters. A second study reported no differences in any measured parameter following caloric stimulation of the SCC.
- Meta-analysis of two studies that evaluated VOR revealed no difference in VOR gain for combined and right rotation tasks, and a small difference for the left rotation task that bordered on statistical insignificance.
- One study that used off-vertical rotation to evaluate otolith function reported greater side-to-side asymmetry in response for AIS participants as evidenced by a higher horizontal directional preponderance, but no difference in vertical asymmetry between groups. A second study that evaluated cervical muscle reflex activity following otolith stimulation reported no differences between or within groups for the majority of measured parameters.

The studies included in this review have reported small and inconsistent differences in various measures but overall, the majority of evidence suggests no major differences between AIS and control participants in vestibular function. The small body of evidence that does exist is, in the main, poorly reported and involves very small sample sizes, therefore it is likely that further research will have an important impact on the current evidence base and may lead to a change in this evaluation.

3.2.7 Brain testing

A number of studies have utilised different methods to assess cortical function in AIS. These included electroencephalograms (EEG), transcranial magnetic stimulation (TMS), and testing of somatosensory-evoked potentials (SEP). These will be reviewed separately in the following sections.

3.2.7.1 Somatosensory-evoked potentials (SEP)

SEPs are used to assess somatosensory system function and can identify sensory abnormalities at the spinal and cortical level. Seven studies that tested SEPs in AIS and control participants were identified. Three studies were excluded due to insufficient information to make an accurate comparison [63-65]. One was excluded because the ages of the control group and AIS participants were not sufficiently similar to make a fair comparison - all controls were 12 yrs old whereas AIS participants ranged from 10-20yrs [66]. The ratio of female: male participants was also very different between the two groups.

(i) Characteristics of included studies

Summaries of the included studies are provided in Table 3.8. Studies were conducted in the USA [67], Spain [68] and Hong Kong [69]. Sample sizes ranged from 12 to 91 AIS and 12 to 49 control participants. The age of the participants was similar between studies ranging from 14.4 to 15.4yrs. All studies matched groups by age with further matching by height, sex and ethnic origin in two studies [67, 68]. Details of the ratio of female:male participants were not reported by one study [67] and one study only included female participants [69]. Fernandez-Bermejo et al [68] reported a difference in the proportion of females between groups with 54% and 77% in the control and AIS group respectively.

Amongst AIS participants, the mean Cobb angle was similar in two studies ranging between 36 [67] and 38.5 [69] degrees. The third study did not report the mean Cobb angle but stated that 65% of AIS participants had angles between 10-19 degrees with the remaining 35% between 20-35 degrees [68]. Reporting of curve types and direction was inconsistent with one study not reporting on this category at all [67], one reporting only location but not direction [68] and the third providing details of both, indicating a predominance of right thoracic curves. One study stated that none of the AIS participants had undergone spinal correction surgery [68]. The other two studies provided no details in this regard [67, 69].

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.12. All included studies were deemed to be at uncertain risk of bias overall. Brinker et al [67] was judged at low risk of classification, measurement and reporting bias but at uncertain risk of selection bias due to insufficient information regarding AIS and control participants. Fernandez-Bermejo et al [68] was at uncertain risk across all categories of selection, classification, measurement and reporting biases due to lack of relevant information, whereas Chau et al [69] was at low risk of selection and classification bias but at uncertain risk of measurement and reporting bias as they did not provide complete details of assessor blinding and data collection procedures.

(iii) Results

Included studies either reported on conduction velocity or conduction time following peripheral nerve stimulation. Due to the difference in outcome measures, they were reviewed separately.

SEP velocity - Brinker et al [67] evaluated conduction velocity at the spinal and cortical levels following stimulation of the posterior tibial and median nerves respectively. Results from both tests suggested no differences between AIS and control participants and no indication of any asymmetry between left and right sides (Spinal combined sides: MD -3.1 m/sec, 95% CI -9.51 to 3.31; cortical combined: MD 3.8 m/sec, 95% CI -0.08 to 7.68).

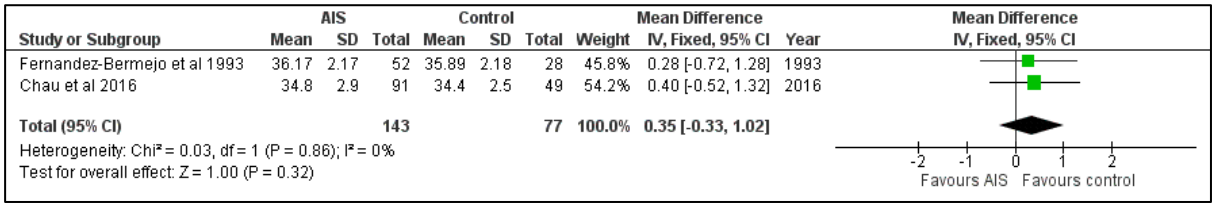
SEP conduction time - Two studies reported SEP conduction time following stimulation of the posterior tibial nerve [68, 69]. Fernandez-Bermejo et al [68] reported results at the both the spinal and cortical level whereas Chau et al [69] only reported on cortical conduction times.

At the spinal level, no differences were reported between AIS and control participants for measurements at T12 and L3 (T12: MD 0.13 ms, 95% CI -0.54 to 0.8; L3: MD 0.14 ms, 95% CI -0.51 to 0.79) [68].

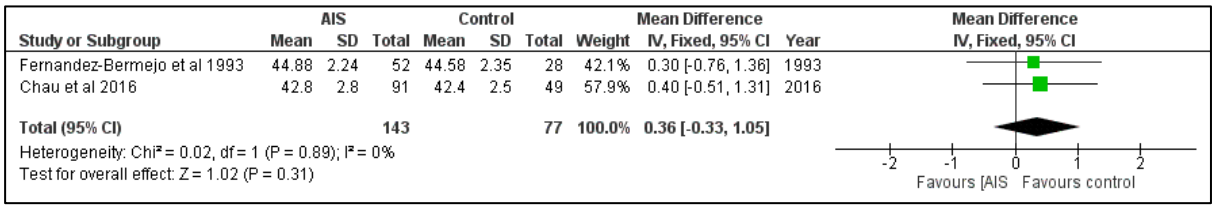
The results of two studies that evaluated cortical SEPs were combined in a meta-analysis [68, 69] and forest plots displayed in Figure 3.12a and b. The two plots are for the first positive (P37) and negative (N45) components of the SEP which normally occur around 37 and 45ms post-stimulus respectively. These indicate that there is no difference between AIS and control participants in SEP conduction time (P37: MD 0.35 ms, 95% CI -0.33 to 1.02, n=220; N45: MD 0.36 ms, 95% CI -0.33 to 1.05, n=220).

Figure 3.12 Forest plots for cortical SEP conduction time (ms)

a) P37



b) N45



3.2.7.2 Transcranial magnetic stimulation (TMS)

Two studies were identified that used TMS to investigate the motor cortex in AIS and control participants.

(i) Characteristics of included studies

Summaries of the included studies are provided in Table 3.8. Studies were conducted in Greece [70] and Spain [71] with sample sizes ranging from 9 to 43 AIS and 8 to 31 control participants.

The age of the participants was similar between studies (mean AIS group: 13yrs and 14.3yrs; mean control group: 12yrs and 14.0yrs) with Domenech et al [71] matching AIS and control participants by age. One study included female participants only [70] while the other provided no details regarding sex of the participants [71].

One study included AIS participants with right sided curves and Cobb angles between 20-40 degrees [70]. In contrast, AIS participants in Domenech et al [71] had right sided curves with Cobb angles ranging from 43 to 68 degrees (mean Cobb 47 degrees). All of these were in the thoracic region whereas Kimikidis et al [70] did not specify curve location in their report. Kimikidis et al also did not describe whether any of the AIS participants had undergone treatment, whereas 1 participant in Domenech et al had received surgery and 7 used braces.

(ii) Risk of bias assessment

Evaluations of the included studies for risk of bias are summarised in Table 3.12. One study was at uncertain risk of selection, classification and measurement bias due to poor reporting of key domains, and at high risk of reporting bias due to a failure to report all outcomes fully [70]. The other study was at low risk of classification bias and uncertain risk of selection and measurement bias. They were also at high risk of reporting bias as they failed to provide results from all measures undertaken [71].

(iii) Results

Although the two included studies used TMS to assess the motor system, they used different testing procedures and evaluated different outcomes. Therefore, the results of each will be discussed separately.

The primary objective of Kimiskidis et al [70] was to investigate whether cerebral asymmetries are implicated in AIS by recording EMG responses in the upper and lower limb following TMS stimulation of the motor cortex (Table 3.8). Parameters investigated included corticomotor thresholds, cortex-to-muscle latency, and wave characteristics including amplitudes. Measures were conducted unilaterally to allow side-to-side comparisons. Their results suggested no statistically significant differences, either side-to-side or combined, between AIS and control participants for any measured upper or lower limb parameters. Note that the results of measures were inconsistently reported across both upper and lower limb.

Domenech et al [71] investigated motor cortico-cortical excitability by measuring motor-evoked potentials (MEP) in the upper limb following conditioning and test stimuli at various interstimulus intervals using paired-pulse TMS. Short interstimulus intervals result in inhibition of MEPs and lower amplitudes whereas longer intervals facilitate MEPS and result in larger amplitudes. The authors did not report comparisons between AIS and control participants for combined left and right hemisphere stimulation. These were performed for this review using the available study data, the results of which suggest no overall differences on average between AIS and control participants (MD 51.92, 95% CI -6.1to 110). In contrast, when interstimulus intervals were sub-grouped into short intervals of 1-6ms characteristic of intracortical inhibition (SICI), and long intervals of 8-20ms (intracortical facilitation, ICF), statistically significant differences were calculated, with AIS participants recording larger amplitudes than control participants for both SICI and ICF interstimulus interval groups (SICI: MD 46.9, 95% CI 3.5 to 90.3; ICF: MD 58.2, 95% CI 3.6 to 112.8).

The authors did report statistically significant differences between AIS and control participants in MEP amplitude following left cerebral hemisphere stimulation (Table 3.8), with mean amplitudes for AIS participants greater than control participants for combined interstimulus intervals (AIS left combined: mean 149.5, SD 48.9; control left combined: mean 73.7, SD 39.4, p=0.02; MD 75.8, 95% CI 33.8 to 117.8) and SICI and ICF interstimulus interval groups. They reported no statistically significant between-group differences following right hemisphere stimulation.

Combined with their reporting of statistically significant side-to-side within-group differences in AIS participants (but not controls), the authors concluded that this demonstrated significant hemispheric asymmetry of cortical excitability in AIS participants. However, summary statistics were not provided for within-group analyses and reanalysis of the data for this review revealed that there were no side-to-side differences for overall (MD 48.9, 95% CI -10.5 to 108.4, n=9) and SICI intervals (MD 44.1, 95% CI -3.9 to 92.2) in AIS participants. The only significant differences were for ICF intervals (MD 55.0, 95% CI 3.6 to 106.4, n=9).

3.2.7.3 Electroencephalograms

Four studies were identified that used electroencephalograms (EEG) to assess brain function in AIS and control participants. Three of these were excluded: two studies used an inappropriate

control group (a cohort from >10 years previously) [23, 72], and in one study, over 50% of AIS participants had undergone spinal correction surgery [73].

(i) Characteristics of included studies

A summary of the included study is provided in Table 3.8. The one included study [74] was conducted in Greece and included 67 AIS and 42 age-matched control participants aged between 11-16yrs (AIS: mean 14yrs SD 0.7; controls: mean 14.1yrs SD 1.0). However, the proportion of females was different between the AIS (76%) and control (48%) groups. No details were provided of the curve types amongst AIS participants. 51% of AIS participants had mild curves (10-15 degrees) and the remaining 49% had curves of greater than 15 degrees although no information was provided regarding whether they were moderate or major.

(ii) Risk of bias assessment

Evaluation of the included study for risk of bias is summarised in Table 3.12. The one included study [74] was judged as at uncertain risk of bias across all key domains due to insufficient information.

(iii) Results

Qualitative evaluation of EEG recordings were made and results were categorised as normal or abnormal. A similar process was undertaken for EEGs following a provocation test. Dretakis et al [74] reported that a greater proportion of AIS participants had abnormal EEG recordings compared to control participants and this difference was statistically significant (AIS: 33% (22/67); controls 14% (6/42), $p<0.005$). Similar results were reported following provocation tests (AIS: 57% (38/67); controls: 22% (9/45), $p<0.001$).

3.2.7.4 Summary

The studies of brain function included in this review have used a variety of methodologies to investigate the motor and somatosensory systems due to suggestions that AIS may be the expression of a sub-clinical disorder of the CNS. These have generally involved only one or two studies for each methodology type, been poorly reported and consequently of uncertain to high risk of bias, and three of the seven studies have involved very small sample sizes (≤12 in each group).

To summarise:

- One study of overall brain function using EEG concluded that AIS participants display a greater frequency of EEG abnormalities than non-scoliotic controls.
- Three studies of the somatosensory system using SEP suggest that there are no significant sensory abnormalities in people with AIS.
- Two studies that examined the motor cortex with TMS had conflicting results with one study with a larger sample size concluding there were no differences between AIS and control participants; the other study reported some differences between AIS and control participants but failed to report other comparisons that revealed no difference, and made errors with other analyses which, after re-analysis for this review, also provided results that suggested little to no cortical asymmetry within AIS participants. The very small sample size (17 in total) and consequent large variation (demonstrated by the wide confidence intervals), also call into question the validity of their results.

Therefore, it remains uncertain whether there are any alterations in brain function associated with AIS based on the results of the included studies. Further research is likely to have an important impact on the evidence base and may lead to a change in this evaluation.

3.2.8 Other

Three studies assessed other forms of neurophysiological measures in AIS and control participants. Two of these were excluded due to insufficient reporting of data [75, 76]. One study evaluated a non-spinal perceptual system using dichotic listening [77].

(i) Characteristics of included studies

A summary of the included study [77] is provided in Table 3.9. It was conducted in Ireland with a sample size of 31 AIS and 20 control participants, each group predominantly female. The age of the participants was similar between groups with mean ages ranging from 14.1yrs to 14.5yrs. No matching of AIS and control participants was reported.

Curve severity ranged from 11-68 degrees and included both directions and all curve locations. No details as to current or previous treatment of AIS participants were provided.

Dichotic listening involves simultaneous presentation of separate words or sounds to each ear. Subjects generally only consciously perceive one of the word-pairs. The difference in attention to left or right stimuli indicates the degree of lateralisation of the brain areas related to speech perception, which in this study, was considered a proxy for asymmetrical organisation of the perceptual system as a whole.

(ii) Risk of bias assessment

Goldberg et al [77] was considered to be at low risk of selection bias and at uncertain risk of classification, measurement and reporting bias (Table 3.12).

(iii) Results

The results of the dichotic listening test were summarised using an asymmetry index where zero is equivalent to perfect symmetry and 1 indicates complete asymmetry (i.e. recognition of words presented to only of the ears). A statistically significant difference was reported between groups suggesting that AIS participants displayed greater asymmetry in speech perception than control participants (AIS: mean 0.43, SD 0.22; controls: 0.30, SD 0.20, between mean difference 0.13, 95% CI 0.01 to 0.25, p=0.035). No analysis was performed to test whether this was associated with the severity or direction of the spinal curve.

(iv) Summary

The results of one study suggest that greater asymmetry of speech perception is found in people with AIS compared to people without AIS. This study has not been repeated to date, has a relatively small sample size, and is at uncertain risk of bias. The validity of the assumption that asymmetry in speech perception is an indicator of asymmetry in the perceptual and cortical system as a whole is also unclear. Therefore, the results of this study should be interpreted with caution and further research is likely to have a substantial impact on the evidence base.

3.3 Discussion

The aim of this systematic review was to establish whether there were any neurophysiological differences between people with AIS and people without AIS. If present, they may provide evidence indicating potential alterations in body schema in people with AIS and provide some rationale as to how an altered body schema may be involved in the development of AIS.

Seven main areas were identified in the literature, each of which were evaluated and where possible meta-anlayses conducted. The results for these suggest the following:

Balance - the results of meta-analyses suggest there is some evidence that people with AIS have poorer static standing balance than people without AIS, although this applied to eyes open condition only. Other measures of balance revealed inconsistent results.

Proprioception - there were inconsistent findings from two studies with one providing some evidence of reduced proprioception in the knee in people with AIS and a second study reporting no difference in testing of the neck.

Vibration testing - the result of meta-analyses of 3 studies suggest some evidence to suggest that people with IAS have lower vibration detection thresholds than people without AIS.

Perception of vertical - the result of meta-analyses of 2 studies suggested no differences between AIS and control participants although one study provided some evidence for poorer subjective postural alignment in people with AIS when tested with eyes closed.

Vestibular function - two studies each of SCC and otolith function produced inconsistent results and meta-analyses of VOR activity suggested no differences between people with AIS and people without AIS.

Brain function - meta-analyses of 2 studies of SEP suggested no difference between AIS and control participants; 2 studies of TMS produced inconsistent results and 1 study of EEG provided some evidence to suggest that there is a greater frequency of abnormal EEGs in people with AIS compared to people without AIS.

Other - one study of a non-spinal perceptual system reported significant asymmetry in speech perception in people with AIS although it is not clear of the relevance of these findings to AIS.

Looking at these results overall, the evidence regarding neurophysiological deficits in AIS is very limited and does not offer any definitive conclusion as to their presence or not. Apart from balance, there were generally few studies informing each subject area of the review. Even when more than one study was available, the differences in measured outcomes and methodologies made it very difficult to compare results and conduct meta-analyses, and resulted in significant clinical and statistical heterogeneity. Differences that were reported were often small and of uncertain clinical significance. Very poor reporting across most studies led to almost universal uncertainty in risk of bias and further reduced confidence in study findings. The majority of studies also involved very small sample sizes and it was often not clear whether AIS and control participants were representative of their respective populations, nor whether they were appropriately matched. All these limitations resulted in uncertainty as to whether the studies were powered sufficiently and conducted well enough to be able to detect any differences.

3.3.1 Previous reviews

Three previous reviews examined some of the areas covered in this systematic review.

Catanzariti et al [78] conducted a systematic review of studies of vestibular function and SVV in people with AIS. Their findings of inconsistency in study results were similar to those of this current review, with the authors concluding that there was not enough evidence to determine any association between vestibular dysfunction and AIS. It should be noted that they did not attempt any meta-analyses.

Dufvenberg et al [79] conducted a systematic literature review and meta-analysis of studies of postural stability in people with AIS. Their results are consistent with the balance findings of this review with moderate evidence suggesting that people with AIS demonstrate poorer static standing balance than controls.

An earlier review by Schlosser et al [6] conducted a best-evidence synthesis of studies of abnormalities associated with AIS, including SEP and dynamic balance. They concluded that there was weak evidence for asymmetry of SEP and moderate evidence of poorer balance control in people with AIS compared to people without AIS.

3.3.2 Limitations

Although this review followed the PRISMA guidelines [1] there were a number of limitations. Only studies in English or with an English translation were included. The grey literature was not explored and the small number of studies involved meant that it was not possible to investigate potential publication bias or bias due to missing results. Previously mentioned limitations with the included studies prevented meta-analysis of many outcomes and reduced the strength of any findings.

3.3.3 Summary

This review found some evidence that static standing balance control is reduced in people with AIS. Inconsistency of results and limitations of included studies resulted in no definitive conclusions regarding the presence of other neurophysiological deficits. Well conducted and well reported studies using an agreed set of common outcomes for each area of study, along with greater care in selecting and matching case and control participants, are required to make definitive conclusions about neurophysiological abnormalities in AIS. As it is likely that any differences that occur in people with AIS are likely to be very small and sub-clinical in nature, it is important that any testing methodology is well designed and sensitive enough to detect small differences, and that sufficient sample sizes are used to be able to provide sufficient power to produce results with any level of confidence.

The findings of this review have implications for the role of body schema in AIS. It weakens the argument that altered body schema plays a role in the development of AIS as no definitive findings of deficits in neurophysiological function relevant to body schema have been identified to date in AIS. This does not prove that these deficits do not exist, just as a causal effect would not be established if the findings of this review had encountered evidence linking body schema and AIS, due to the studies involved being observational in nature. However, it also highlights the lack of well conducted and well reported studies examining this area of study and paves the way for further research to improve the current evidence base.

Table 3.3 Summary of findings - Balance

		participant characteristics							observed variables			
study	group	n	age (yrs)	sex (F:M)	Cobb (degrees)	curve type(s)	prior treatment	other	description	n (analysed)	result	authors' conclusion
Driscoll et al 1984	AIS	31	12.9 (2), range 9-16	31:0	24.6 (11.5), range 7-55	?	?	-	**Static balance, 1) Sharpened Romberg** (sec), **2) Beam walk** (steps), **3) Beam stand EO** (sec), **4) Beam stand EC** (sec), **5) 1 leg stand EC** (sec), **a) right, b) left**	31[a]	**1.** 158 (78.8), **2.** 9.4 (4.1), **3.** 13.4 (11.6). **4.** 44.2 (46.9), **5a.** 82 (49.9), **5b.** 80.6 (49.4)	No sig diff among the groups on any of the tests. This test battery could not distinguish the control group from the experimental group. No correlation between balance score and degree of curvature in AIS subjects.
	control	23	11.3 (2.4), range 7-15	23:0	NA	NA	NA	-		23[a]	**1.** 168 (77.2), **2.** 11.7 (4.1), **3.** 21 (17.4), **4.** 53 (53.8), **5a.** 95 (52), **5b.** 83 (48)	
Adler et al 1986	AIS	91	12.6 (1.5), range 9-16	91:0	23.2 (10.9), range 5-57	40 R, 11 L, 21 double, 19 ?	observation, bracing, electrical stimulation	risser sign 1.6 (1.6), tanner stage 3.4, menarche 52%	**Force plate testing COP 1) Quiet standing (dispersion) a) EO, b) EC; 2) Romberg test (dispersion), a) EO, b) EC**	91	**1a.** 6.0 (0.2), **1b.** 6.8 (0.2)*, **2a.** 13.6 (0.4), **2b.** 19.4 (0.5)	with EC, AIS subjects showed sig less postural sway on static balance tests (p<0.05). No sig diff for AIS subjects between types of treatment.
	control	57	12.6 (1.5), range 9-16	57:0	NA	NA	NA	age matched		57	**1a.** 6.2 (0.2), **1b.** 7.6 (0.3)*, **2a.** 14.1 (0.5), **2b.** 20.3 (0.6)	
Chen et al 1998	AIS	30	16.6 (3.8), range 11-21	28:2	range 22-67	King type I: 8, II: 11, III: 4, IV: 3, V: 4	untreated	-	**Force plate testing COP - Quiet standing 1) sway area** (cm^2), **a) EO, b) EC**; **2) lateral sway** (cm), **a) EO, b) EC**; **3) sagittal sway** (cm), **a) EO, b) EC**; **4) sway radius** (cm), **a) EO, b) EC**	30[a]	**1a.** 765 (419)*, **1b.** 791 (425)*, **2a.** 17 (6.8)*, **2b.** 18 (7.4)*, **3a.** 25.9 (13.2), **3b.** 26.3 (15.7), **4a.** 9.3 (3.9)*, **4b.** 8.9 (2.7)	sagittal sway (AP direction) was not significantly different between normal subjects and AIS patients for both eyes opened and closed. However, the difference in lateral sway was significant.
	control	15	16.8 (3.1) range 14-20	13:2	NA	NA	NA	-		15[a]	**1a.** 447 (98)*, **1b.** 558 (215)*, **2a.** 13.4 (5.1)*, **2b.** 12.2 (3.8)*, **3a.** 20.4 (4.2), **3b.** 23.2 (7.1), **4a.** 7.3 (2.7)*, **4b.** 8.1 (3.1)	
Nault et al 2002	AIS	43	12.5 (1.7)	43:0	29 (12), range 7-52	39 RT, 2 RTL, 2 RL	no active treatment	-	**Force plate testing COP - Quiet standing EO, a) COP sway area** (cm^2); **b) COM sway area** (cm^2)	43[a]	**a.** 27.4 (15.4)*, **b.** 21.8 (13.4)*	The scoliotic group was characterized by a decrease in standing stability, as indicated by a 44% and 60% statistically significant increase in the COP and COM sway area respectively compared with that of the able-bodied subjects.
	control	38	12.9 (2)	38:0	NA	NA	NA	-		38[a]	**a.** 19.0 (12.4)*, **b.** 13.7 (8.4)*	
Bennett et al 2004	AIS	14	14 (2.1)	12:2	range 5-35	King type I: 4, II: 6, III: 4	no surgery	-	**Force plate testing COP - quiet sitting EC, a) normalised sway area** ($x10^{-3}$); **b) normalised sagittal sway** ($x10^{-3}$); **c) normalised lateral sway** ($x10^{-3}$)	14[a]	**a.** 0.13 (0.01)*, **b.** 2.73 (1.1)*, **c.** 1.89 (0.69)*	The area of the 85% ellipse of the controls was more than three times larger than that of the children with scoliosis (P <0.02). The root mean square values of the normalized COP for the control group were more than 50% larger in both the ML (P<0.02) and the AP directions (P<0.05).
	control	12	13.7 (1.8)	8:4	NA	NA	NA	age matched		12[a]	**a.** 0.43 (0.46)*, **b.** 4.18 (2.6)*, **c.** 3.05 (1.57)*	
Guo et al 2006	AIS	105	range 11-14	105:0	range 10-35	?	?	-	**Force plate testing COP - Sensory Organisation Test (SOT), a) somatosensory ratio; b) visual ratio; c) vestibular ratio**	105	**a.** 0.98 (0.03), **b.** 0.76 (0.13), **c.** 0.52 (0.19)	no sig diff between groups.
	control	57	range 11-14	57:0	NA	NA	NA	-		57	**a.** 0.98 (0.02), **b.** 0.77 (0.13), **c.** 0.52 (0.17)	
Bruyneel et al 2010	AIS	12	11.8 (0.8)	12:0	30.2 (9.7), range 19-45	12 RT	brace & physiotherapy	Risser sign 1.4 (0.6)	**Force plate testing dynamic balance - seated destabilisation task** (N)**, 1) Sagittal sway, a) EO, b) EC; 2) Lateral sway, a) EO, b) EC**	12[a]	**1a.** 26.8 (23.2)*, **1b.** 23.4 (16.5)*, **2a.** 10 (5.2)*, **2b.** 9.4 (4.5)*	The adaptive spatio-temporal responses to destabilisation by AIS subjects in the seated position observed here were characterised by an increase in the excursion of the GRF and an increase in the variability of the parameters analysed compared to controls (p<0.001 all).
	control	15	13.0 (0.8)	?	NA	NA	NA	-		15[a]	**1a.** 7.5 (4.3)*, **1b.** 7.4 (4.3)*, **2a.** 4.5 (1.6)*, **2b.** 4.4 (2.1)*	

LT=left thoracic, RT=right thoracic, LTL=left thoracolumbar, RTL=right thoracolumbar, LL=left lumbar, RL=right lumbar
EO = eyes open; EC = eyes closed; COP = centre of pressure; COM = centre of mass
[a] assumed as not actually stated
[b] data combined for this review, e.g. both limbs, both directions
[c] data in text and tables inconsistent
* statistically significant difference between groups
all values mean (SD) unless stated

		participant characteristics							observed variables			
study	group	n	age (yrs)	sex	Cobb	curve	prior	other	description	n	result	authors' conclusion
Kuo et al 2010	AIS	22	13.91 (1.54), range 11-17	?	T: 28 (9.9), range 8-42; L: 26.2 (9), range 10-45	22 double (RT/LL)	no surgery	-	**Force plate testing COP dynamic balance, 1a) Balance index, a) EO, b) EC, c) sponge pad; 2) Sagittal tilt angle** (degrees), **a) EO, b) EC, c) sponge pad; 3) Lateral tilt angle** (degrees), **a) EO, b) EC, c) sponge pad**	22[a]	**1a.** 0.95 (0.5) **1b.** 3.8 (1.9)*, **1c.** 0.76 (0.3)*, **2a.** 3.1 (1.6)*, **2b.** 9.2 (5.0)*, **2c.** 2.73 (1.26)*, **3a.** 2.9 (1.3)*, **3b.** 9.0 (5.4)*, **3c.** 2.60	AIS patients achieved smaller posture tilting angle for all conditions (p<0.05) and a lower balance index (ie better balance) than normal subjects with EC (p<0.05).
	control	22	14.5 (1.0), range 13-16	?	NA	NA	NA	age matched		22[a]	**1a.** 1.1 (0.3) **1b.** 6.6 (2.0)*, **1c.** 1.05 (0.4)*, **2a.** 4.3 (1)*, **2b.** 16.5 (3.7)*, **2c.** 5.52 (3.1)*, **3a.** 7.3 (2)*, **3b.** 16.3 (1.1)*, **3c.** 3.70 (1.98)*	
Kuo et al 2011	AIS	32	13.7 (2), range 9-17	?	T: 26.6 (10.5), range 6-42; L: 25.8 (8.7), range 10-45	32 double (RT/LL)	no surgery	Risser sign 2.3 (1.1)	**Force plate testing COP dynamic balance EO, 1a) Sagittal tilt angle** (degrees); **1b) lateral tilt angle** (degrees); **2) Destabilisation** (degrees), **a) sagittal tilt, b) lateral tilt**	32	**1a.** 3.0 (1.3)*, **1b.** 2.8 (1.2)*, **2a.** 15.33 (4.66)*, **2b.** 4.32 (1.15)*	the AIS group had less tilting angle than the control group (P <0.05) but higher muscle activities than normal subjects
	control	23	14.6 (1), range 13-16	?	NA	NA	NA	age matched		23	**1a.** 5.5 (2.3)*, **1b.** 4.2 (0.3)*, **2a.** 18.36 (4)*, **2b.** 8.52 (3.47)*	
Kinikli et al 2011	AIS	20	14.5 (2.2), range 10-18	17:3	36.4 (16)	?	no active treatment	-	**Force plate testing COP quiet standing, 1) Sagittal balance index[b], a) EO, b) EC; 2) Lateral balance index[b], a) EO, b) EC**	20	**1a.** 210.4 (196.8), **1b.** 648.8 (580.2), **2a.** 210.4 (151.7), **2b.** 648.8 (553.9)	There was no statistical difference in BI score between patients with AIS and healthy controls during eyes open and eyes closed conditions (p>0.05).
	control	28	15.1 (1.7), range 10-18	18:10	NA	NA	NA	-		28	**1a.** 192.7 (120.9), **1b.** 558.5 (411.9), **2a.** 191.3 (89.8), **2b.** 567 (346.0)	
Gruber et al 2011	AIS	36	12.5 (2)	36:0	1^{o}: 39.5 (16.1); 2^{o}: 31.2 (13.4); 3^{o}: 23.6 (11.7)	2 single curves, 15 double curves, 19 triple curves	18 pre-bracing, 18 pre-surgery	-	**Force plate testing COP quiet standing, 1) Sagittal sway** (cm); **2) Lateral sway** (cm); **3) Sway area** (cm^2)	36	**1.** 2.8 (1.1), **2.** 2.9 (2.6)*, **3.** 373 (40)*	AIS had greater lateral sway (p=0.025) and total sway area (p=0.005) compared to controls
	control	10	11.9 (2.8)	10:0	NA	NA	NA	-		10	**1.** 2.5 (1.2), **2.** 1.7 (0.7)*, **3.** 348 (38)*	
Park et al 2013	AIS	128	15.4 (1.8)	?	22.3 (10.3)	?	?	-	**Force plate testing COP target area** (kg/m^2), **1) Sagittal balance; 2) Lateral balance**	128	**1.** 19.7 (14.3)*, **2.** 12.7 (10.5)*	scoliosis groups' left and right lateral and forward/backward balance was unstable compared to the normal group (p<0.01)
	control	15	14.7 (1.7)	?	NA	NA	NA	-		15	**1.** 10.4 (8.5)*, **2.** 2.4 (2)*	
Chang et al 2017	AIS	13	15.7, range 12-18	10:3	T: 17.9 (8.3); TL: 25.2 (9.4); range 7-40	9 RT/LL, 4 LT/RL	no active treatment	-	**Force plate testing COP - quiet standing , 1) Sway** (mm)**, a) normal standing, b) feet together, c) tandem standing**	13[a]	**1a.** 21.8 (5.9), **1b.** 47.5 (23.0), **1c.** 145.2 (48.7)	A non-significant main effect of group (F = 0.35, p = 0.56) on postural stability was found.
	control	13	15.5, range 12-18	9:4	NA	NA	NA	age matched		13[a]	**1a.** 22.6 (9.1), **1b.** 49.1 (16), **1c.** 159.7 (69.8)	
Le Berre et al 2017	AIS	114	14.5 (1.9)	94:20	35.7 (15.3)	114 RT	?	-	**Static balance, 1) Sharpened Romberg** (sec)**, a) right, b) left; 2) 1 leg stand EC** (sec)**, a) right, b) left**	114[a]	**1a.** 22.3 (9.5), **1b.** 23.7 (8.7), **2a.** 19.1 (10.4), **2b.** 19.5 (10.4)	There was no significant difference between the two groups regarding the static tests (right and left Romberg tests and right and left unipedal stance tests).
	control	81	14.1 (1.9)	69:12	NA	NA	NA	age matched		81[a]	**1a.** 24.1 (8.4), **1b.** 24.6 (8.5), **2a.** 20 (9.6), **2b.** 21.2 (9.1)	

LT=left thoracic, RT=right thoracic, LTL=left thoracolumbar, RTL=right thoracolumbar, LL=left lumbar, RL=right lumbar
EO = eyes open; EC = eyes closed; COP = centre of pressure; COM = centre of mass

[a] assumed as not actually stated

[b] data combined for this review, e.g. both limbs, both directions

[c] data in text and tables inconsistent

* statistically significant difference between groups

all values mean (SD) unless stated

Table 3.4 Summary of findings - Proprioception

		participant characteristics							observed variables			
study	group	n	age (yrs)	sex (F:M)	Cobb (degrees)	curve type(s)	prior treatment	other	description	n (analysed)	result	authors' conclusion
Barrack et al 1984	AIS	17	mean 14.8	14:3	mean 26.8	17 RT	7 brace, 3 surgery, 7 none	-	**1. Joint angle reproduction - knee:** mean difference between actual and estimated angle (degrees)[b]; **2. motion detection threshold - knee**: mean distance moved before movement detected (degrees)[b]	17[a]	**1.** mean 5.1 (SD 2.5)*; **2.** mean 2.6 (SD 1.8)*	AIS greater error in reproducing knee joint angle (p<0.01) and higher knee motion detection threshold (p<0.05) than controls
	control	12	?	?	NA	NA	NA	age matched		12[a]	**1.** mean 2.7 (SD 1.5)*; **2.** mean 1.4 (SD 0.6)*	
Guyot et al 2016	AIS	30	mean 15.5 (SD 1.5)	?	mean 24.8 (SD 9.5)	11 RT, 13 LL or LTL, 6 RL or RTL	?	-	**joint angle reproduction - neck**: mean difference between actual and estimated angle (degrees)[b,c]	30	mean 3.52 (SD 1.31)	40% (12/30) AIS subjects, error was pathological (>4.5 degrees); significant difference in mean error between these and remaining AIS (p=0.00048) and controls (p=0.034)
	control	14[c]	mean 14.6 (SD 2.0)	?	NA	NA	NA	-		12[c]	mean 3.30 (SD 1.72)	

LT=left thoracic, RT=right thoracic, LTL=left thoracolumbar, RTL=right thoracolumbar, LL=left lumbar, RL=right lumbar

[a] assumed as not actually stated

[b] data combined for this review, e.g. both limbs, both directions

[c] data in text and tables inconsistent

* statistically significant difference between groups

all values mean (SD) unless stated

Table 3.5 Summary of findings - Vibration

	Participant characteristics								observed variables			
study	group	n	age (yrs)	sex (F:M)	Cobb (degrees)	curve type(s)	prior treatment	other	description	n (analysed)	result	authors' conclusion
Wyatt et al 1986	AIS	20	14.4, range 12.4 to 16.1	20:0	30, range 20 to 44	11 double (RT/LL), 7 RTL, 2 RT	?	-	**1. Sensitivity** - threshold for vibration detection (microns), **a) ulnar styloid, b) great toe, c) 1st MTP joint, d) medial malleolus**; **2. symmetry** - absolute diff between L/R sides (microns), **a) ulnar styloid, b) great toe, c) 1st MTP joint, d) medial malleolus**	20 (40 sides)	**1a.** 0.27 (0.07), **1b.** 0.33 (0.01), **1c.** 0.27 (0.10), **1d.** 0.52 (0.16); **2a.** 0.06 (0.04), **2b.** 0.07 (0.09), **2c.** 0.05 (0.06), **2d.** 0.07 (0.06)	At all four test sites, the scoliotics were more senstive in ability to detect vibration, showing significantly lower thresholds (p<0.001). Greater asymmetry in 2/4 test sites for AIS than controls (p=0.007 and 0.011) - not correlated with curve magnitude/direction. No sig diff at other two sites.
	control	20	14.5, range 12.4 to 16.1	20:0	NA	NA	NA	-		20 (40 sides)	**1a.** 0.38 (0.01), **1b.** 0.48 (0.09), **1c.** 0.43 (0.08), **1d.** 0.67 (0.15); **2a.** 0.04 (0.03), **2b.** 0.03 (0.02), **2c.** 0.02 (0.02), **2d.** 0.08 (0.08)	
Barrack et al 1988	AIS	58	15.4, range 11.8 to 18.7	58:0	35, range 20-52	?	?	-	**Sensitivity** - threshold for vibration detection (microns), **a) ulnar styloid, b) great toe, c) 1st MTP joint**	58	**a.** 0.25 (0.09), **b.** 0.29 (0.12), **c.** 0.25 (0.11)	scoliotic group was more sensitive than controls, demonstrating significantly lower threshold values (p<0.001) at all test sites. Significant asymmetry not found in AIS compared to controls.
	control	57	14.5, range 11.9 to 18.8	57:0	NA	NA	NA	age/sex matched		48[a]	**a.** 0.30 (0.08), **b.** 0.37 (0.10), **c.** 0.34 (0.10)	
McInnes et al 1991	AIS	14	14.6 (1.1)	14:0	35 (14), range 15 to 56	6 RT, 3 LTL, 2 LL, 2 double (RT/LL)	?	-	**Sensitivity** - threshold for vibration detection at 1st MTP joint (microns)	14	0.76 (0.52)	Vibratory thresholds were significantly higher in AIS than controls (p=0.05). No sig asymmtery for AIS or control group. Because of questions regarding the reliability of the equiment, we believe that neither our results nor those of Wyatt et al can be used to support the hypothesis that a lesion of the posterior column is a cause of AIS.
	control	22	13.6 (1.7)	22:0	NA	NA	NA	-		22	0.45 (0.28)	

all values mean (SD) unless noted

L=left convex, R=right convex, LT=left thoracic, RT=right thoracic, LTL=left thoracolumbar, RTL=right thoracolumbar, LL=left lumbar, RL=right lumbar

[a] 9 later suspected of scoliosis

* statistically significant difference between groups

all values mean (SD) unless stated

Table 3.6 Summary of findings - Perception of vertical

		participant characteristics							observed variables			
study	group	n	age (yrs)	sex (F:M)	Cobb (degrees)	curve type(s)	prior treatment	other	description	n (analysed)	result	authors' conclusion
Cakrt et al 2011	AIS	23	mean 14.5 (SD 2.5), range 8-18	18:5	mean 21.4 (SD 8.8), range 11-36	7 RT, 2 LT, 5 RTL, 9 LTL	no surgery	-	**1. Subjective visual vertical (SVV)** - difference between perceived and actual vertical (degrees); **2. SVV variable error** - variability of difference between perceived and actual vertical (degrees)	23[c]	**1.** mean 0.86 (SD 1.39)*; **2.** mean 2.46 (SD 0.82)*	The groups differed significantly on SVV deviation ($p < 0.01$) and SVV uncertainty (variable error) ($p < 0.001$). The main finding is that patients with IS have abnormal SVV perception.
	control	23	mean 14.0 (SD 2.9)	18:5	NA	NA	NA	age/sex matched		23[c]	**1.** mean -0.04 (SD 0.64)*; **2.** mean 1.50 (SD 0.94)*	
Chang et al 2017	AIS	13	mean 15.65, range 12-18	10:3	mean thoracic 17.88 (SD 8.29), mean TL 25.18 (SD 9.44), overall range 7 to 40	9 RT-LL, 4 LT-RL (9 double curve, 1 single curve, 3 triple curves)	no active intervention	-	**1. SVV** - number of correct evaluations (% correct) ; **2. SVV reaction time** - time to make valid evaluation (ms)	13[c]	**1.**mean 76 (SD 17); **2.** mean 650.58 (SD 156.03)	No main effect of group ($F = 0.17$, $p = 0.69$) on SVV accuracy. The SVV accuracy of the AIS group was comparable to that of the controls. For reaction times, no simple main effect of group was noted ($p > 0.05$).
	control	13	mean 15.54, range 12-18	9:4	NA	NA	NA	age matched		13[c]	**1.** mean 78 (SD 10); **2.** mean 626.24 (SD 115.3)	
Le Berre et al 2019	AIS	30	mean 14.23 (SD 1.75)	30:0	mean 31.97 (SD 12.88), range 17-74	30 RT	?	matched by age (±1 year), body mass index (±10%), right- or left-handedness, and maturity using Tanner staging (±1)	**1. Subjective visual vertical, a) static, b) dynamic** - difference between perceived and actual vertical (degrees); **2. Subjective postural vertical** - difference between perceived postural vertical and actual vertical (degrees)	30	**1a.** Mean 0.23 (SD 1.49), range -4.75 to 4.17; **1b.** 0.06 (SD 2.85), range -6.5 to 6.45[b]; **2.** 2.13 (SD 2.22)*, range -1.67 to 7.93	For SVV-S and SVV-D, no significant difference between the AIS and control group. For SPV, difference with the control group was very significant: p=.00023. The number of AIS patients with abnormal SPV was 10-fold that observed in controls.
	control	30	mean 13.93 (SD 1.85)	30:0	NA	NA	NA			30	**1a.** Mean -0.40 (SD 0.9), range -2.57 to 1.55; **1b.** 0.18 (SD 4.23), range -9.88 to 11.88[b]; **2.** -0.08 (SD 1.4)*, range -2.13 to 3.13	

L=left convex, R=right convex, LT=left thoracic, RT=right thoracic, LTL=left thoracolumbar, RTL=right thoracolumbar, LL=left lumbar, RL=right lumbar

[a] 10-16yr old participants only

[b] data combined for this review, e.g. both limbs, both directions, age groups

[c] assumed as not actually stated

* statistically significant difference between groups

all values mean (SD) unless stated

Table 3.7 Summary of findings - Vestibular Function

			participant characteristics							observed variables			
	study	group	n	age (yrs)	sex (F:M)	Cobb (degrees)	curve type(s)	prior treatment	other	description	n (analysed)	result	authors' conclusion
SCC direct stimulation	Jensen & Wilson 1979	AIS	18	range 11-15	18:0	range 5 to 45	10 RT, 2 RTL, 1 LT, 4 LTL, 1 LL	?	-	**1. Southern California postrotatory nystagmus test (SCPNT), a) duration** - sum of both directions (secs), **b) excursion category** (%), **c) rhythm category** (%)	18	**1a.** 43.9 (12.5)*, range 27 to 71.2; **1b.** 25% 'normal' excursion[b]; **1c.** 27.8% 'normal' rhythm[b]	diff between AIS and controls in postrotatory nystgamus - duration sig decreased and increased frequency of abnormal excursion and rhythm in AIS compared to controls.
		control	25	range 11-15	25:0	NA	NA	NA	age matched		25	**1a.** 52.0 (11.3)*, range 30 to 81; **1b.** 42% 'normal' excursion[b]; **1c.** 42% 'normal' rhythm[b]	
	Hitier et al 2015	AIS	17	15.5 (1.8)	13:4	26.7 (8.3), range 15-40	8 T, 4 TL, 5 L (8 R, 6 L, 3 double)	untreated		**Caloric tests - a) mean eye speed** (degrees/sec), **b) diff in mean eye speed R/L direction, c) canal paresis** (%), **d) participants with abnormal canal paresis** (%)	16	**a.** 34 (15.6), **b.** 1.95 (1.8), **c.** 18.3 (4.1), **d.** 37.5% (6/16)	no sig diff in measures (p= 0.25, 0.26 and 0.52 respectively). Higher freq AIS had abnormal (>15%) canal paresis but difference to controls not statistically significant
		control	9	16.7 (1.5)	6:3	NA	NA	NA	recruited from schools		9	**a.** 41.8 (15.4), **b.** 2.03 (2.03), **c.** 11.6 (1.7), **d.** 11.1% (1/9)	
VOR testing	Simoneau et al 2009	AIS	10	17.4	9:1	range 28-51	RT	untreated	-	**VOR gain, a) Left rotation, b) Right rotation, c) combined**	10	**a.** 0.99 (0.06), **b.** 1.02 (0.07), **c.** 1.01 (0.07)	AIS underestimated magnitude of rotation to greater extent than controls (p<0.05).
		control	13	16.4	11:2	NA	NA	NA	age matched		12	**a.** 1.00 (0.1), **b.** 1.02 (0.1), **c.** 1.01 (0.09)	
	Pialasse et al 2015	AIS	36	15.2 (1.6)	28:8	27.9 (10.1)	?	21 brace, 6 conservative	Risser sign 4.0 (1.1), menarche 32/36	**VOR gain, a) Left rotation, b) Right rotation**	36	**a.** 0.92 (0.03), **b.** 0.95 (0.05), c. 0.94 (0.04)	no main effect of Group ($F(2, 47) = 0.52$, $p > 0.05$) or Direction ($F(1, 47) = 2.2$, $p > 0.05$); no Group by Direction interaction ($F(2, 47) = 0.73$, $p > 0.05$).
		control	16	14.6 (2.8)	13:3	NA	NA	NA	menarche 15/16		14	**a.** 0.90 (0.02), **b.** 0.95 (0.03), **c.** 0.93 (0.04)	
Otolith testing	Wiener-Vacher & Mazda 1998	AIS	30	12 (median 12), range 6.5-15	27:3	37.5 (median 35), range 10-85	16 T, 5 TL, 9 L (18 R, 12 L)	?	-	**OVAR test - a) difference in mean horizontal eye speed R/L direction** (degrees/sec), **b) difference in mean vertical eye speed up/down direction** (degrees/sec)	30	**a.** 1.3 (1.1), **b.** 0.98 (1.1)	mean value of horizontal DP in AIS sig greater than controls (p=0.004). No sig diff in vertical DP. Greater proportion of AIS displayed 'abnormal' responses than controls (66.7% 20/30 v 0/12).
		control	12	12 (median 12.5), range 11-15	10:2	NA	NA	NA	-		12	**a.** 0.4 (0.3), **b.** 0.9 (0.7)	
	Pollak et al 2013	AIS	29	13.5 (2.5), range 9-23	25:4	50, range 28-72	23 double, 6 T (27 R, 2 L)	?	-	**vestibular-evoked myogenic potentials (VEMP)**[b], **a) P13 latency** (ms), **b) N23 latency** (ms), **c) amplitude** (microV), **d) amplitude asymmetry ratio**	29	**a.** 13.5 (1.5), **b.** 21.5 (2.3)*, **c.** 70.9 (38.1)*, **d.** 22.5 (15.9)	P13 latencies comparable both groups, AIS significantly longer N23 latencies than controls both sides. VEMP amplitudes significantly higher AIS (i.e. better response) than controls. The amplitude Asymmetry Ratio was similar in both groups.
		control	19	?	9:10	NA	NA	NA	age matched		19	**a.** 13.1 (2.3), **b.** 19.6 (2.7)*, **c.** 47.7 (36.4)*, **d.** 31.9 (19.8)	

all values mean (SD) unless indicated

L=left convex, R=right convex, LT=left thoracic, RT=right thoracic, LTL=left thoracolumbar, RTL=right thoracolumbar, LL=left lumbar, RL=right lumbar

VOR = vestibulo-ocular reflex; OVAR = off-vertical axis rotation

[a] assumed as not actually stated

[b] data combined for this review, e.g. both limbs, both directions, age groups

* statistically significant difference between groups

all values mean (SD) unless stated

Table 3.8 Summary of findings - Brain function

			participant characteristics							observed variables			
	study	group	n	age (yrs)	sex (F:M)	Cobb (degrees)	curve type(s)	prior treatment	other	description	n (analysed)	result	authors' conclusion
SEP	Brinker et al 1992	AIS	12	14.6, range 12 to 16.6)	?	36 (6), range 30 to 52	?	?	-	**1. Spinal levels** - conduction velocity of SEP following stimulation of posterior tibial nerve (m/sec), **a) Right, b) Left, c) combined**; **2. Cortical levels** - conduction velocity of SEP following stimulation of median nerve (m/sec), **a) Right, b) Left, c) combined**	12[a]	**1a.** 37.6 (4.9), **1b.** 40.3 (4.1), **1c.** 39.0 (4.7); **2a.** 54.3 (4.1), **2b.** 53.5 (6.5); **2c.** 53.9 (5.5)	no sig diff (p>0.05) were found between scoliotic and control children for SSEP conduction velocities in either the spinal cord or proximal to the Cx spine (centrally). No significant asymmetry in conduction velocities was found in either group.
		control	12	14.7, range 12.2 to 16.4	?	0	NA	NA	age, sex, height and race matched		12[a]	**1a.** 41.5 (10.6), **1b.** 42.6 (9.9), **1c.** 42.1 (10.3) ; **2a.** 50.0 (3.7), **2b.** 50.1 (4.4), **2c.** 50.1 (4.1)	
	Fernandez-Bermejo et al 1993	AIS	52	14.9 (1.7), range 13-19	40:12	34 participants 10-19 degrees; 18 participants 20-35 degrees	9 T, 14 TL, 13 double, 12 L, 4 other	no surgery	44 participants Risser 3-5 and/or post-pubertal	**1. Spinal levels**[b] - conduction time of SEP following stimulation of posterior tibial nerve (msec) at, **a) L3, b) T12**; **2. Cortical levels**[b] - conduction time of SEP following stimulation of posterior tibial nerve (msec), **a) P37, b) N45**	52[a]	**1a.** 17.23 (1.43), **1b.** 17.87 (1.52); **2a.** 36.17 (2.17), **2b.** 44.88 (2.24)	no stat sig diff observed for any parameter when AIS compared to controls. No assymmetry in conduction times for either AIS or control groups.
		control	28	15.4 (1.6), range 13-19	15:13	NA	NA	NA	age, height, population origin matched		28[a]	**1a.** 17.09 (1.42), **1b.** 17.74 (1.43); **2a.** 35.89 (2.18), **2b.** 44.58 (2.35)	
	Chau et al 2016	AIS	91	14.4	91:0	38.5 (20.7)	64 RT, 12 L, 15 double	?	-	**Cortical levels**[b] - conduction time of SEP following stimulation of posterior tibial nerve (ms), **a) P37, b) N45**	91	**a.** 34.8 (2.9), **b.** 42.8 (2.8)	Severe AIS with major right thoracic curve and Cobb angle of over 40 degrees showed significant prolonged SEP latency on the right side compared to controls and increased inter-side P37 latency difference compared to moderate AIS and controls.
		control	49	14.6	49:0	NA	NA	NA	age matched		49	**a.** 34.4 (2.5), **b.** 42.4 (2.5)	
TMS	Kimiskidis et al 2007	AIS	43	13 (2)	43:0	range 20-40	43 R	?	-	**1) Cortico-motor threshold**[b], **upper limb**; **2) Silent period** (ms)[b], **upper limb**; **3) CMCT** (ms)[b], **a) upper limb, b) lower limb; 4) Cortex-muscle latency - lower limb** (ms)[b], **a) rest, b) facilitated 5) MEP amplitude - lower limb**[b], **a) rest, b) facilitated**	43[a]	**1.** 40.1 (7.8), **2.** 127.5 (34.9), **3a.** 3.8 (0.7), **3b.** 13.2 (3.1), **4a.** 39.1 (2.5), **4b.** 38.0 (2.8), **5a.** -2.4 (1.3), **5b.** -1.9 (1.3)	Detailed upper limb testing revealed normal findings. Therefore, our results do not support the concept of a generalized brain asymmetry in IS or the existence of pathological alterations in the corticospinal tracts to upper limbs.
		control	31	12 (2)	31:0	NA	NA	NA	-		31[a]	**1.** 43.5 (7.1), **2.** 130.7 (34.9), **3a.** 3.7 (0.7), **3b.** 13.4 (1.6), **4a.** 39.0 (2.5), **4b.** 37.8 (2.9), **5a.** -1.9 (1.2), **5b.** -1.8 (1.2)	
	Domenech et al 2010	AIS	9	14.3 (1.6)	?	47, range 43-68	9 RT	1 surgery, 7 brace	Risser sign <4	**Cortical excitability** - TMS induced MEP abductor pollicis brevis (% baseline test stimuli), **1) Overall, a) Left hemisphere; b) Right hemisphere; 2) SICI, a) Left hemisphere, b) Right hemisphere; 3) ICF, a) Left, b) Right**	9	**1a.** 149.5 (48.9)*, **1b.** 100.5 (40.5), **2a.** 112.6 (29.5)*, **2b.** 68.5 (18.5), **3a**. 195.7 (9.8)*, **3b.** 140.6 (8)	AIS greater MEP amplitude post-left hemispheric stimulation compared to controls (p=0.02). Right hemisphere, IS slight increase all ISI potentials but no statistical significance (p=0.06). SICI left hemisphere significantly greater AIS than controls. SICI right hemisphere greater in AIS than controls, but no statistical significance. ICF larger left hemisphere AIS as compared to controls. Right ICF greater AIS but this no statistical significance.
		control	8	14.0 (0.7)	?	NA	NA	NA	age matched		8	**1a.** 73.7 (39.4)*, **1b.** 72.5 (40.8), **2a.** 44.7 (25.3)*, **2b.** 42.4 (21.8), **3a.** 109.8 (12.2)*, **3b.** 110.1 (20.5)	
EEG	Dretakis et al 1988	AIS	67	14.1 (1), range 11-16	51:16	10-15 degrees: 34, >15 degrees: 33	?	?	-	**1) EEG results** (n, %), **a) normal, b) abnormal; 2) EEG results post provocation** (n, %), **a) normal, b) abnormal**	67	**1a.** 45/67 (67%), **1b.** 22/67 (33%)*, **2a.** 29/67 (43%), **2b.** 38/67 (57%)*	results show that scoliotic children had sig greater incidence of abnormal EEGS compared to controls (p<0.05; provoked p<0.001).
		control	42	14.5 (1), range 11-16	20:22	NA	NA	NA	age-matched		22	**1a.** 36/42 (86%), **1b.** 6/42 (14%)*, **2a.** 33/42 (78%), **2b.** 9/42 (22%)*	

all values mean (SD) unless stated

L = left convex, R = right convex, LT=left thoracic, RT=right thoracic, LTL=left thoracolumbar, RTL=right thoracolumbar, LL=left lumbar, RL=right lumbar

TMS = transcranial magnetic stimulation; MEP = motor-evoked potential; SICI = short-interval intracortical inhibition; ICF = intracortical facilitation; CMCT = central motor conduction time

[a] assumed as not actually stated

[b] data combined for this review, e.g. both limbs, both directions

* statistically significant difference between groups

Table 3.9 Summary of findings - Other

	particicpant characteristics								observed variables			
study	group	n	age (yrs)	sex (F:M)	Cobb (degrees)	curve type(s)	prior treatment	other	description	n (analysed	result	authors' conclusion
Goldberg et al 1995	AIS	31	14.5 (1.8), range 11-18	29:2	31.0 (13.8), range 11-68	23 RT, 2 LT, 1 RTL, 4 LTL, 1 LL	?	-	**Dichotic listening test - asymmetry index**	31	0.43 (0.22)*	the results demonstrate greater asymmetrical cortical function (in this case, cognitive linguistic function) in AIS compared to controls (p=0.035) suggesting asymmetry of cortical structures and interconnections
	control	20	14.1 (2.4), range 11-20	19:1	NA	NA	NA	-		20	0.30 (0.20)*	

LT=left thoracic, RT=right thoracic, LTL=left thoracolumbar, RTL=right thoracolumbar, LL=left lumbar, RL=right lumbar
* statistically significant difference between groups
all values mean (SD) unless stated

Table 3.10 Risk of bias - Balance

	Balance													
criteria	Adler et al 1986	Chen et al 1998	Nault et al 2002	Kinikli et al 2011	Gruber et al 2011	Chang et al 2017	Park et al 2013	Kuo et al 2010	Guo et al 2006	Bennett et al 2004	Driscoll et al 1984	Le Berre et al 2017	Bruyneel et al 2010	Kuo et al 2011
are cases clearly defined and representative?	✓	✓	✓	?	✓	✓	?	?	?	✓	?	?	✓	?
are controls representative of general adolescent population, and comparable to cases?	✓	?	?	?	?	✓	?	?	?	?	?	?	?	?
Were the same incl/exclusion criteria used for AIS and healthy adolescents?	?	?	?	✓	?	?	?	?	✓	?	?	✓	?	?
clearly established that controls are non-cases (as well as possible)?	✓	?	?	✓	?	?	?	✓	✓	?	✓	?	?	✓
Was other pathology excluded that possibly influences the outcome?	?	?	?	✓	✓	?	?	✓	✓	?	?	✓	?	✓
Was the data collection performed in the same standardized way for AIS cases and healthy adolescents?	?	?	✓	✓	✓	?	✓	✓	✓	?	✓	✓	✓	✓
Were the observers blinded to AIS/healthy adolescent status?	?	?	?	?	?	?	?	?	?	?	✓	?	X	?
Free of selective reporting of outcomes?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Potential confounders identified and taken into account?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Risk of Bias verdict:	unclear	unclear	unclear	unclear	unclear	unclear	unclear	unclear	unclear	unclear	unclear	unclear	high risk	unclear

Table 3.11 Risk of bias - Proprioception, Vibration Threshold and Perception of Vertical

	Proprioception		Vibration threshold			Perception of vertical			
criteria	Barrack et al 1984	Guyot et al 2016	Wyatt et al 1986	Barrack et al 1988	McInnes et al 1991	Cheung et al 2002	Cakrt et al 2011	Chang et al 2017	Le Berre et al 2019
are cases clearly defined and representative?	?	✓	?	?	?	?	✓	✓	?
are controls representative of general adolescent population, and comparable to cases?	?	?	?	?	?	?	✓	✓	?
Were the same incl/exclusion criteria used for AIS and healthy adolescents?	?	✓	?	?	?	?	?	?	✓
clearly established that controls are non-cases (as well as possible)?	?	✓	✓	✓	✓	?	✓	?	✓
Was other pathology excluded that possibly influences the outcome?	?	✓	?	?	✓	✓	✓	?	✓
Was the data collection performed in the same standardized way for AIS cases and healthy adolescents?	✓	✓	✓	✓	✓	✓	✓	?	?
Were the observers blinded to AIS/healthy adolescent status?	?	?	?	✓	✓	?	X	?	?
Free of selective reporting of outcomes?	✓	X	✓	✓	✓	✓	✓	✓	✓
Potential confounders identified and taken into account?	?	?	?	?	?	?	?	?	✓
Risk of Bias verdict:	unclear	unclear	unclear	unclear	unclear	unclear	high risk	unclear	high risk

Table 3.12 Risk of bias - Vestibular function, Brain function and Other

	SCC		VOR		Otolith		SEP			TMS		EEG	other
criteria	Jensen & Wilson 1979	Hitier et al 2015	Simoneau et al 2009	Pialasse et al 2015	Wiener-Vacher et al 1998	Pollak et al 2013	Brinker et al 1992	Fernandez-Bermejo et al 1993	Chau et al 2016	Kimikidis et al 2007	Domenech et al 2010	Dretakis et al 1988	Goldberg et al 1995
are cases clearly defined and representative?	?	✓	?	✓	✓	?	?	✓	✓	?	✓	?	✓
are controls representative of general adolescent population, and comparable to cases?	?	?	?	?	X	X	?	?	✓	?	?	?	✓
Were the same incl/exclusion criteria used for AIS and healthy adolescents?	✓	✓	?	?	✓	?	?	?	?	?	?	?	?
clearly established that controls are non-cases (as well as possible)?	✓	✓	?	?	?	?	✓	?	✓	?	✓	?	✓
Was other pathology excluded that possibly influences the outcome?	✓	✓	✓	?	✓	?	✓	✓	✓	?	✓	?	?
Was the data collection performed in the same standardized way for AIS cases and healthy adolescents?	✓	?	✓	✓	✓	?	✓	?	?	?	?	?	?
Were the observers blinded to AIS/healthy adolescent status?	?	?	?	?	?	?	✓	?	?	?	?	✓	?
Free of selective reporting of outcomes?	✓	✓	✓	✓	X	✓	✓	?	✓	X	X	✓	✓
Potential confounders identified and taken into account?	?	?	?	?	?	?	✓	?	?	?	?	?	?
Risk of Bias verdict:	unclear	unclear	unclear	unclear	high risk	high risk	unclear	unclear	unclear	high risk	high risk	unclear	unclear

4 How to measure body schema

The previous chapter described a systematic review of neurophysiological function in people with AIS compared to non-scoliotic controls. Some of the outcomes included in the review are of relevance in the study of body schema. The question then becomes, how best to measure body schema in AIS.

As described in Chapter 2, investigations of body schema in chronic pain conditions provide a useful model for testing of body schema in scoliosis. Various methodologies have been utilised in chronic pain conditions to describe aspects of sensorimotor performance that are thought to be associated with body schema. These include tests of tactile acuity, left/right judgement (laterality discrimination), spatial perception and proprioception. Some tests of these properties involve equipment and protocols that are only possible to conduct in a laboratory-type environment, and require extensive knowledge and experience along with appropriate financial resources to perform testing reliably. The setting in which recruitment and testing was conducted for the studies that form the basis of this thesis did not allow for such sophisticated evaluations. Therefore, this chapter will describe testing methodologies that are better suited to a clinical environment and that were able to be used to gather data on body schema in people with AIS for the studies that contribute to this thesis.

4.1 Tactile acuity

Tactile acuity refers to the precision or accuracy in determining various properties of touch sensation. Testing of tactile acuity has used a number of different methodologies. Two of the most common of these include testing two point discrimination thresholds and ability to locate the site of stimuli applied to relevant parts of the body.

4.1.1 Two point discrimination threshold testing

Two point discrimination threshold (TPDT) testing is a test of tactile spatial acuity and was initially designed for assessing neural recovery following injury and/or surgery to the nerves of the hand/fingers. It involves the application of two mechanical stimuli simultaneously to the skin using calipers or similar devices (Figure 4.1). Depending on a variety of factors, the points will either be perceived as two separate stimuli or a single stimulus. Repeated testing using

different distances between the two points enables the determination of a 'threshold' distance - stimuli applied with a distance between them greater than the threshold will generally be perceived as two separate stimuli, whereas if the distance is less than threshold, the brain will not be able to distinguish accurately between them and it will be perceived as a single stimulus. The initial premise was that the lower the threshold, the greater the level of neural repair and potential for return of function.

Figure 4.1 Example of instrument used for TPDT testing

The threshold distance varies depending on the part of the body being tested. For example, the lips and the hands are much more sensitive (and therefore have a lower threshold) than the back. This is largely due to variations in the density and distribution of the touch receptors in the skin and is also reflected in the size of the area specific to each body part in the primary sensory cortex, illustrated by the 'homuncular man' of chapter 2 (Figure 2.1). As such, TPDT also depends on the integrity of the cortical representation of the body area being tested [1]. For this reason, TPDT testing has been used not just as a measure of peripheral nerve function, but also as a means of assessing the state of the representation of the body within the somatosensory cortex and therefore, as a measure of body schema [2].

The following sections will examine the measurement properties and procedures of TPDT testing with an emphasis on the trunk and spinal regions.

4.1.1.1 Normative values

Normative TPDT values for the spine have been reported as part of a recent reliability study by Catley et al [3] involving 28 healthy, pain-free subjects. Mean thresholds for the neck (C7 region) and lumbar spine (L3 region) were 45.9 mm (SD 18.4) and 55.5 mm (SD 12.7) respectively. This is in accordance with other studies that have evaluated the spine (Table 4.1) [1, 3-12].

Table 4.1 Normative values for TPDT, mean mm (SD)

Study	n (sex, age)	Lumbar spine	Thoracic spine	Neck
Nolan 1985	43 (26M, age 20-24yrs)	49.9(12.7)	52.2 (12.6)	55.4 (20)
Moseley 2008	10 (5M, 29-58 years)	50.1 (6.33)	-	-
Wand et al 2010	19 (5M, age 34 yrs SD 12.1)	44.2 (13.7)	-	-
Luomajoki & Moseley 2011	45 (20M, age 41 yrs SD 10)	vertical 43.2 (14.8) horizontal 45.0 (11.3)	-	-
Stanton et al 2013	18 (7M, age 41 yrs SD 11)	45.28 (5.12)	-	-
Catley et al 2013	28 (19M, age 24.1 yrs SD 4.7)	55.5 (12.7)	-	45.9 (18.4)
Elsig et al 2014	30 (5M, age 37.2 yrs SD 13.5)	-	-	29.75 (7.0)
Falling & Mani 2016	group I: 23 (8M, age 23 yrs SD3.4)	60.7 (17.9)	-	-
	group II: 20 (11M, age 34.9 yrs SD 2.6)	60.05 (14.85)	-	-
	group III: 18 (11M, age 45.5 yrs SD 3.0)	69.1 (10.14)	-	-
	group IV: 18 (10M, age 54.2 yrs SD 2.4)	76.9 (14.21)	-	-
Elgueta-Cancino et al 2017	20 (9M, age 28.5 yrs SD 5)	vertical 32.5 (9.63) horizontal 51.0 (11.9)	-	-
Spahr et al 2017	20 (age 39 yrs SD 9.91)	49.8 (6.5)	-	-
Harvie et al 2017	22 (12M, age 23.9 yrs SD 6.8)-	-	-	35.2 (9.6)

4.1.1.2 Measurement properties

Catley et al [3] also evaluated intra- and inter-rater reliability of TPDT testing of the neck and lumbar spine in 28 clinicians with varying levels of experience. For the neck, results indicated good reliability for both intra- and inter-rater testing (intra: Intraclass correlation coefficient (ICC) 0.79, 0.59-0.90 95% CI; inter: ICC 0.81, 0.63-0.91 95% CI). For the lumbar spine, the results suggested good and moderate reliability respectively (intra: ICC 0.81, 0.63-0.91 95% CI; inter: ICC 0.66, 0.38-0.82 95% CI). Results did not differ according to level of clinician expertise. However, the wide confidence intervals for lumbar spine inter-rater reliability suggests that, where possible, only one clinician should be involved in evaluating TPDT in the lower back. A more recent study evaluated test-retest reliability in the neck region. One trained rater assessed 22 healthy participants twice, with a 30 minute interval between tests [12]. The results were similar those described above (ICC 0.85, 0.67 to 0.94 95% CI, $p<0.001$).

The minimal detectable change for the lumbar spine and neck has been calculated at 15mm and 24mm respectively [3]. There was a large difference between repeat evaluations indicating that TPDT testing, although reliable, is not very precise. Similar results were reported by Wand et al [13] who calculated that a change of at least 13-17mm would be required to provide 95% reliability of a true difference in TPDT in the lumbar spine. The same authors suggested that, in an effort to reduce inter-subject variation when testing clinical populations, differences could be analysed between the painful and the non-painful side in the case of unilateral conditions, or to other adjacent non-painful body regions (e.g. contralateral side or the thoracic spine for unilateral or bilateral CLBP respectively).

The large variability reported in these studies could be due to other factors that have been shown to influence the threshold distance. Skin type, age, temperature, level of attention and testing methodology have all been reported to affect testing results [3] along with increased body mass index [9]. Frequent testing or practice may also result in a learning effect although this appears to be short lived and require intensive repetition (e.g. [14]). Other studies evaluating TPDT in the lumbar spine have not found evidence for either fatigue or a learning effect under normal, less intensive testing conditions [3].

4.1.1.3 Testing procedures

Most studies involving TPDT testing use procedures based on those of Moberg [15] for the hand and fingers. These have since been developed further and applied to other parts of the body with more accurate or purpose-designed instrumentation. Currently, the standard format for TPDT testing is to use a series of alternating ascending and descending trials, often referred to as the 'staircase' method (e.g. [2]). This involves starting with a set distance between the two points and then gradually increasing or decreasing the distance by a set amount at each subsequent test. Variations to this include gradually reducing the size of the 'step' (i.e. the change in distance between the points) between each set of trials in an attempt to more finely pinpoint the threshold.

Despite widespread use, there have been some criticisms of this methodology. For example, it is possible that subjects may understand the principle of the method and therefore be able to anticipate the sequence of stimuli being applied during an ascending or descending trial, potentially biasing their responses [16]. To this end, 'catch' trials are also often included. This involves tests where just one point is used to ensure participants are not guessing. However, these do not completely control for the potential response bias.

Peters & Schmidt [17] proposed using a different approach entirely. Rather than starting at a set distance between the two points and then gradually increasing or decreasing by a set distance as per standard practice, they randomised the order that each point-to-point distance was presented, thereby eliminating the possibility of anticipation by the subject. Disguising the true intention and the mechanics of the testing procedure from the subject is another method of attempting to reduce response bias.

Another potential criticism of TPDT testing is that responses may also be biased when the two points are not presented simultaneously. Even a small time gap can provide temporal cues that allow the subject to more accurately determine that two points have been presented rather than one. To this end, subjects are routinely instructed to inform the tester if they feel two points as a result of them not being applied at the same time. However, it is unclear as to how effective these instructions are in minimising this effect.

Other, more rigorous methods of testing tactile spatial acuity have been proposed to counter the effect of temporal bias, such as the Grating Orientation Task (GOT) [18]. Although now

considered the gold standard, the equipment required render it impractical to use in most clinical situations and has not been tested in the trunk or spinal regions.

A test that attempts to combine the simplicity of standard TPDT testing with the rigour of the GOT has also been developed. The Two Point Orientation Discrimination Threshold test [19] requires subjects to determine whether the twin points of a caliper are orientated in a vertical or horizontal direction as opposed to distinguishing between one or two points as in traditional TPDT testing. The threshold is thus determined by the distance at which they are unable to distinguish the orientation thereby eliminating the possibility of temporal cues that may occur in traditional TPDT testing when the points are not applied simultaneously. Unfortunately, the study describing this test was published towards the end of recruitment and testing for this thesis and thus was not utilised.

4.1.2 Localisation

To localise where the body has been touched requires knowledge of the location and distribution of sensory receptors in the skin, anatomical knowledge (e.g. body size, shape and configuration), as well as the position of the relevant body part, both in relation to other parts of the body and to the external environment. This involves higher-order body representations that integrate information from multiple sensory modalities [20, 21], which matches the definition of body schema as defined in chapter two. Therefore, localisation represents one method of measuring the properties of body schema [21].

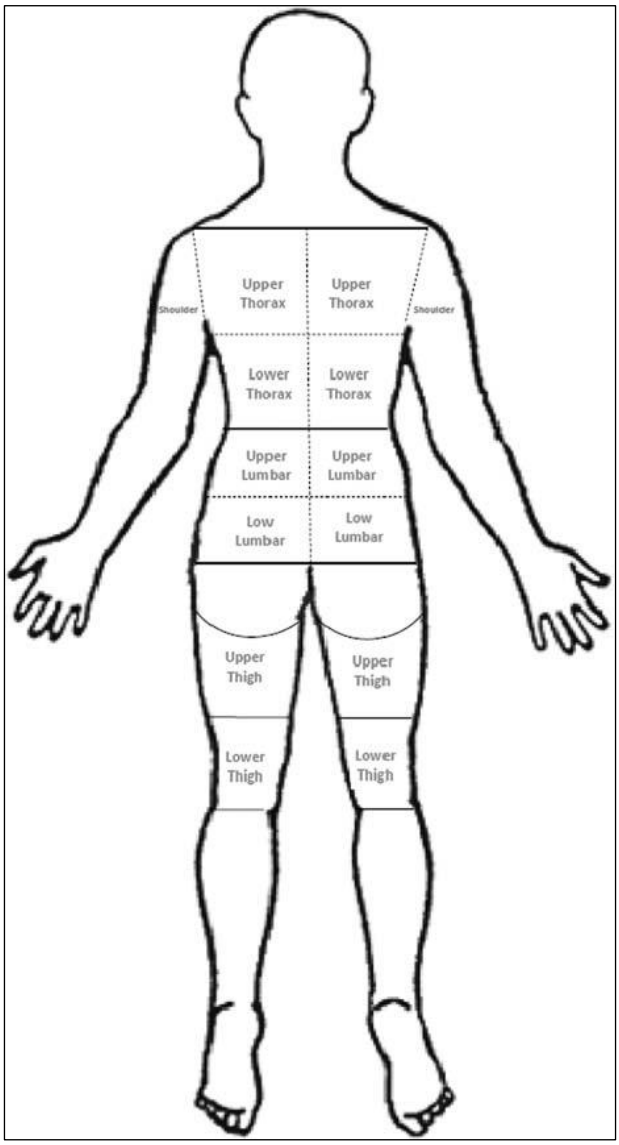
Tactile localisation has been investigated extensively in the hand and forearm but rarely in other parts of the body. Typically, studies have focussed on the distance between the actual and perceived stimulus locations, and have used specialist equipment that generally is not practical for clinical settings [20]. Recently, two studies have used a simpler methodology to assess the distance between perceived and actual stimulation site in the lower back and neck regions [22, 12]

Tactile localisation has also been used as a treatment modality in chronic pain conditions such as phantom limb pain [23], CRPS [24] and CLBP [25]. These studies have evaluated the effect of tactile discrimination training on pain, function and cortical reorganisation with promising results. However, few studies have investigated localisation ability as an outcome in these conditions.

4.1.2.1 Normative values

In the only known study assessing tactile localisation of the back, 24 patients with CLBP were tested along with an equal number of healthy controls [26]. The posterior surface of the trunk and upper thigh were divided into 7 regions and a stimulus was applied twice to each of these in random order resulting in 14 trials overall per participant (Figure 4.2). The participants were asked to name the site of each stimulus by referring to a schematic body diagram illustrating the site of possible stimulus locations.

Figure 4.2 Test regions for tactile localisation evaluation



(from [26])

Rather than measuring the distance between actual and perceived stimulus location, this protocol measured whether participants were able to name the correct body region, with the resulting number of errors recorded. CLBP patients were assessed on the most painful side whereas the side for controls was randomly assigned.

Although ostensibly investigating referred sensations, data was also collected for correct and incorrect responses. From a total of 336 trials in each group (14 trials x 24 participants), 326 correct and 10 incorrect responses were recorded for the control participants (97% correct) versus 294 and 42 respectively for the CLBP patients (87.5% correct). They reported that 66.7% (16/24) of CLBP patients made at least one error compared to only 25% (6/24) of control participants (Fisher exact p=0.034). Statistics for accuracy were not provided but could be calculated by extracting the required data from the published results. This resulted in figures for mean accuracy per participant of 98.3% (96.8-99.7% CI 95%) and 92.7% (90-95.5% CI 95%) for controls and CLBP patients respectively. This equated to a mean of 0.4 errors per participant in the control group versus 1.75 in the CLBP group. The results of this trial represent the only normative data of localisation accuracy available for the back region.

However, a study evaluating localisation accuracy in the neck has recently been conducted by Harvie et al [12]. This study involved 12 vibrotactile stimulators applied to the skin of the neck in a grid-like arrangement. Thirty separate stimuli were applied in random order and participants were asked to indicate the location of each via a computer tablet with the grid-pattern superimposed on a photo of the neck. The mean accuracy in locating the stimulated site was 54.9% (SD 13.9) which was much less than the localisation accuracy for the back region described above. The differences probably reflect the size of the test regions used in each trial and therefore, the distance between stimulus locations that participants were asked to distinguish between. In the back study, the distance between stimulation sites was very large, whereas for the neck study, the distance between sites was small.

4.1.2.2 Measurement properties

Two studies have attempted to evaluate the reliability of localisation testing. The first was of the forearm and used a protocol of measuring distance between perceived and actual stimulus location [21]. This involved 10 healthy participants (7 M, mean age 26yrs, SD 3) who underwent testing on successive days. On each occasion, seven sites were stimulated sixty times each resulting in a total of 420 stimuli. The participant indicated the site of stimulation

by tapping on an image of their arm presented on a computer tablet. The authors concluded that test-retest reliability was high based on the high level of correspondence between the results of each days' testing (0.68 to 0.93 ICC at each site).

Only one study has investigated reliability in the spinal region. Participants in the neck localisation accuracy study (n=22) by Harvie et al were tested again 30 minutes after initial assessment [12]. Test-retest results indicated good reliability although confidence intervals were very wide (ICC 0.60, 0.25 to 0.81 95% CI, p=0.002).

A number of factors have been reported as influencing localisation ability. There are reports that, when faced with uncertainty in determining stimulus location, participants demonstrate a bias towards the centre of the relevant body part [20]. This effect is especially pronounced for weak stimulus intensities. When higher intensities are used, participant responses are more consistent and accurate [27]. It is thought that increasing the area and duration of stimulus has a similar effect [27].

Studies of the forearm have also reported greater localisation accuracy when a stimulus is applied nearer to body part boundaries (e.g. the elbow or wrist) [20]. Age is another factor with reports of localisation accuracy reaching maturity at age 10 to 12 years [28]. Vision of the affected body part, posture and direction of gaze have also been reported as influencing localisation ability [21]. None of these factors have been investigated in the trunk or spinal regions.

4.2 Laterality discrimination

Laterality discrimination is the ability to identify right from left sides of the body. It is usually tested by viewing a series of images of relevant left and right-sided body parts in different positions and orientations, and measuring the accuracy and reaction time required to make a judgement. A correct response requires mental spatial transformation of an internal representation of the relevant body part to correspond with the viewed image. Therefore, an accurate and timely response is dependent on an intact body schema [29].

4.2.1 Normative data

The majority of studies examining laterality discrimination have involved the hands with very few studies evaluating other parts of the body. Three studies looking specifically at the lower back reported mean accuracy figures of 86 to 98% in healthy controls, with corresponding mean reaction times (correct responses only) ranging from 1719 to 2400 milliseconds [30-32] (Table 4.2). Similar figures have also been reported for the neck region [8, 33].

Table 4.2 Normative values for laterality discrimination

Study	n (sex, age)	Lumbar spine		Neck	
		Accuracy, %	Reaction time, msec	Accuracy, %	Reaction time, msec
Bray & Moseley 2011	14 (5 M; age 43 yrs SD 7)	87 (75-98 95% CI)	2400 (2200-2500 95% CI)	-	-
Wallwork et al 2013	1361 (age range 10-90yrs)	-	-	89.8 (SD 11.3)*	1620 (SD 500)
Bowering et al 2014	429	97.8 (SD 7.2)	1718.75 (SD 968.81)	-	-
Elsig et al 2014	30 (5 M; mean age 37.2yrs SD 13.5)	-	-	76.6 (SD 13.2)	-
Linder et al 2016	30 (10 M; age 43.3yrs SD 9.6)	Right 87.8 (SD 10.2); Left 86.0 (SD 10.4)	Right 2010 (SD 520); Left 2010 (SD 550)	-	-

*median accuracy 92.5%

4.2.2 Measurement properties

Only two studies have attempted to investigate reliability of laterality discrimination testing. Bray and Moseley [30] evaluated test-retest reliability in 5 LBP patients (1 M; mean age 46yrs, SD 16) and 5 control participants (2 M; mean age 40 yrs, SD 4) using images of both hand and trunk regions. Testing occurred over 5 sessions with at least 1 day (mean 4 days; range 1-7) between each session. For the hands, participants had to identify whether each image represented a left or right hand. For the trunk, participants had to identify the direction of movement. Results for the trunk suggested excellent reliability (0.80 to 0.92 ICC and 0.74 to

0.87 ICC for accuracy and reaction times respectively). These were similar to reliability estimates for the hands (Table 4.3).

Linder et al [32] used a similar protocol to evaluate test-retest reliability for laterality discrimination in the trunk and feet in LBP patients and healthy controls. Testing was performed on 3 separate occasions, with a mean of 2.2 days (range 2-5 days) between session 1 and 2, and a mean of 2.4 days (range 1 to 11 days) between sessions 2 and 3. In general, they reported lower estimates than Bray & Moseley [30] with fair-to-excellent reliability for reaction times in the trunk, but only fair-to-good reliability for retesting of accuracy (0.51 to 0.91 ICC and 0.51 to 0.71 respectively). A similar pattern was seen for reliability testing of the feet.

Both of these studies reported large variability in some of the reliability estimates, indicated by wide 95% confidence intervals. The lower limits of some of these intervals were below acceptable levels of reliability [34]. This may be due to the relatively low numbers of participants included in the studies.

Table 4.3 Test-retest reliability for trunk laterality discrimination testing, ICC (95% CI)

Bray & Moseley 2011				
Reliability over all test sessions	Trunk	LBP (n=5)	Control (n=5)	-
	Accuracy	0.92 (0.83-0.97)	0.80 (0.59-0.97)	-
	RT	0.87 (0.73-0.95)	0.74 (0.45-0.90)	-
	Hands	LBP (n=5)	Control (n=5)	-
	Accuracy	0.92 (0.85-0.97)	0.87 (0.74-0.94)	-
	RT	0.70 (0.36-0.88)	0.95 (0.90-098)	-
Linder et al 2016				
Reliability between Test 1 & 2	Trunk	LBP (n=25)	Control (n=27)	overall (n=52)
	Accuracy	0.71 (0.44-0.86)	0.59 (0.28-0.79)	0.64 (0.45-0.78)
	RT	0.51 (0.15-0.75)	0.82 (0.64-0.91)	0.72 (0.56-0.83)
	Feet	LBP (n=24)	Control (n=26)	overall (n=50)
	Accuracy	0.61 (0.29-0.81)	0.82 (0.54-0.89)	0.71 (0.54-0.82)
	RT	0.75 (0.50-0.88)	0.85 (0.69-0.93)	0.83 (0.71-0.90)
Reliability between Test 2 & 3	Trunk	LBP (n=22)	Control (n=25)	overall (n=47)
	Accuracy	0.69 (0.39-0.86)	0.51 (0.15-0.75)	0.59 (0.36-0.75)
	RT	0.91 (0.79-0.96)	0.81 (0.61-0.91)	0.82 (0.70-0.90)
	Feet	LBP (n=21)	Control (n=23)	overall (n=44)
	Accuracy	0.77 (0.52-0.90)	0.84 (0.66-0.93)	0.90 (0.82-0.94)
	RT	0.63 (0.28-0.83)	0.89 (0.77-0.95)	0.85 (0.74-0.91)

Numerous factors have been reported as influencing laterality discrimination testing. The magnitude of image rotation (from 0 to 180 degrees) is positively correlated with increased reaction time and negatively correlated with accuracy. This effect has been described for the hands (e.g. [35]), the neck [33] and the trunk [31]. The increased reaction time and reduced accuracy is thought to reflect the extra time and difficulty required to mentally transform the internal body representation to match that of the viewed image. This links with findings that greater reaction times are correlated with lower accuracy in laterality discrimination [33, 35].

In contrast to previous studies that have reported improved performance when viewing images that correspond to the dominant side [36], testing of laterality discrimination ability in the hands [35] and feet [32] has revealed faster reaction times for images of the right hand/foot compared to the left regardless of handedness, although there was no effect on accuracy. Conversely, images of neck movement to the right were associated with greater accuracy, with no effect on reaction times. This bias for right-sided image processing may reflect an asymmetry in sensorimotor performance [33]. It has yet to be evaluated in the trunk.

In testing laterality discrimination of the neck in adults, increasing age was associated with increased reaction times and reduced accuracy. The same study also reported increased reaction times for female participants compared to males, and left-handers compared to right-handers [33]. These effects of age, gender and handedness have not been found in the trunk or lower back [31, 32].

Two studies have evaluated laterality discrimination in children and young adolescents, both involving testing of the hands. Caeyenberghs et al [37] undertook testing in 58 healthy children divided by age into 3 groups: 7-8, 9-10 and 11-12 years. They reported that 7-8 year olds were significantly slower and less accurate than older age groups but that performance gradually improved with increasing age until 11-12 years, when children reach adult levels of performance.

Similar improvements in accuracy with increasing age were also reported in a study of 57 children (26 M; mean age 11 years, SD 3), although no effect was seen on reaction time [38]. Interestingly, compared to adults, no effect of gender was noted, nor did there appear to be any relation between levels of sporting activity and laterality discrimination ability.

A learning effect has been reported for laterality discrimination. When testing was repeated in 33 healthy adults after 3 weeks, an 8-20% decrease in reaction times and a 3% increase in accuracy was reported for a hand left/right judgement task [39]. Similarly, an improvement in performance, particularly of reaction times, was reported for testing in the lower back [32], with obvious connotations with regard to repeated measures over time in participants.

The posture or position of the body/trunk during testing has not been investigated as a possible confounder in studies involving the trunk or spinal regions, although there have been reports that resting hand position influences reaction times for left/right hand judgement tasks [33]. This may be particularly important when considering hand position while using computers where the participant is required to press a key on a computer keyboard to indicate left and right sides. The most commonly used software for laterality testing allows participants to indicate the side an image corresponds to by either using the left and right arrow keys, which are normally situated to the right of centre, or the 'a' and 'd' keys, which are situated to the left. There is some evidence to suggest that body representations are based on body-centred rather than hand or limb-centred frames of reference, i.e. they are not dependent on whether the right or left hand is used, but on whether the hands are situated in the left or right side of the body reference frame [40]. Therefore, the location of the keys in relation to the body midline may introduce a response bias if not controlled for.

4.3 Spatial perception

As described in Chapter 2, it is thought that a disruption or distortion of body representation plays a role in chronic pain conditions, a process that is likely driven by cortical reorganisation and/or disrupted sensory information. Reports of some of the resulting symptoms that occur in these conditions bear some resemblance to those suffered by patients with hemispatial neglect following brain injury. For example, there have been numerous reports of patients describing a lack of 'ownership' or control, reduced ability to localise the site of touch stimuli and increased difficulty with movement of the affected body part [1, 41]. Alterations in spatial perception, in particular that of body space as defined by judgement of body midline, have also been reported [42] further suggesting a neglect-like process at work.

The ability to accurately perceive the spatial characteristics of both the external environment and the body are crucial to orienting oneself in space and therefore plays a fundamental role in

body schema [43]. Various methodologies have been used in different clinical populations to investigate these properties. They range from laboratory-based direct investigations of perceived body midline to paper-based tests of spatially-orientated attention. Results of testing in patients with hemispatial neglect generally reveal a corresponding response bias to the ipsilateral side of the lesion due to the reduced awareness or attention to the contralateral side (i.e. the side controlled by the injured side of the brain). As this deficit is more commonly seen following injury to the right cerebral hemisphere, results of testing generally involve large deviations to the right of true centre. However in the normal population, despite some inconsistency, most participants reveal a smaller leftward bias, often termed 'pseudo-neglect', which is thought to be due to dominance of the right cerebral hemisphere for spatial tasks [43-45].

Details of studies that have investigated spatial perception in AIS are described in the systematic review in Chapter 3.

The simplest, and most widely used, clinical test for spatially-orientated attention is the line bisection test (LBT) which was initially devised as a test for hemispatial neglect [46]. In its classical form, the LBT is a paper-based test where participants are asked to mark the centre of a horizontal line. The difference between the perceived and actual centre, along with the direction, is measured and often converted to a relative error percentage based on the line length.

4.3.1 Normative values

There have been reports of considerable variation between individuals in performance of the LBT [47, 48]. These have been linked to the wide array of testing protocols that have been used and differences in sample populations. In an attempt to address this issue, an extensive review and meta-analysis was conducted by Jewell & McCourt [45]. Overall, the results confirmed a statistically significant leftward bisection error when performed by neurologically normal subjects. Estimates as to the magnitude of this leftward deviation were not provided.

Establishment of normative values for the magnitude of the deviation is challenging due to considerable variation in the way that different studies have calculated the distance between perceived and actual centre-point of the line. However, a number of studies have used comparable methods that provide some guidance regarding the amount of deviation in healthy

participants (Table 4.4). In these studies, the difference between perceived and actual line centre has been transformed into relative error using the formula:

$$\text{Relative error (\%)} = ((\text{measured left half} - \text{true half})/\text{true half}) \times 100$$

This accounts for the different line lengths that have been used both within and between studies. Overall, the relative error is quite low with figures of between 0 to 4.5% in healthy participants [48-55]. Some studies have also looked at relative error in different age groups as summarised in Table 4.5 [48, 54].

4.3.2 Measurement properties

In a recent study of test-retest reliability, 50 healthy adults (15 M, mean age 22.6 yrs, SD 4.46, range 18-38yrs) repeated a series of spatial attention tasks on two occasions at least 24 hours apart [44]. The tasks included a computer version of the LBT where lines were randomly presented in 9 different positions. Each position was repeated 12 times resulting in a total of 108 tests per participant. Their results confirmed the leftward bias seen in previous investigations of the LBT in healthy adults and that this effect was seen in both testing sessions. Test-retest reliability of the magnitude of the deviation was calculated between session 1 and 2 using Pearson's *r* correlation ($r = 0.846$, $p<0.001$). Earlier studies of test-retest reliability have reported lower correlation coefficients following re-testing at longer time intervals (≥ 2 weeks) [56, 57].

A number of different factors have been reported as influencing the LBT. These were investigated as part of the review by Jewell & McCourt [45] and can be categorised as factors relating to the participant (e.g. age) and those that relate to the test itself (e.g. line length). A summary of the findings is presented in Table 4.6.

Table 4.4 Normative values for LBT % error (mean, SD)

study	n	Line position	Left hand*	Right hand*	Combined
Scarisbrick et al 1987	42 (17 M, 1st year University students)	Combined	-1.81	-0.41	-
Fukatsu et al 1990	24 (12 M, age range 50-70 yrs)	Left	-1.06	2.13	0.54 (3.86)
		Centre	0.53	2.64	1.59 (3.66)
		Right	0.18	1.84	1.01 (3.46)
		Combined	-0.12 (3.69)	2.20 (3.27)	1.04 (3.66)
Brodie & Pettigrew 1996	18 (9 M)	Combined	-2 (6)	-3 (4)	-
Varnava et al 2002	40 (11 M, age range 18-41 yrs)	Combined	-	-	-0.31 (2.22)
Hausmann et al 2002	38 (19 M, age range 22-49 yrs)	Left	−2.85 (0.53)	−3.05 (0.49)	-
		Centre	−2.60 (0.42)	−1.61 (0.41)	-
		Right	−1.32 (0.49)	0.13 (0.50)	-
		Combined	−2.30 (0.39)	−1.52 (0.34)	-
Hausmann et al 2003**	98 (age range 10-53 yrs)	Left	-2.91 (0.83)	-1.04 (0.87)	-
		Centre	-2.28 (0.68)	0.10 (1.34)	-
		Right	-1.53 (0.89)	0.75 (1.53)	-
		Combined	-2.24 (0.62)	-0.04 (1.05)	-
Forderreuther et al 2004	18	Left	-2 (6)	-3 (4)	-
		Centre	1 (6)	0 (6)	-
		Right	2 (5)	2 (6)	-
Pulsipher et al 2009**	46 (19 M, age range 8-18yrs)	Left	−4.47 (0.8)	−2.49 (0.51)	-
		Centre	−1.90 (0.63)	1.95 (0.64)	-
		Right	0.93 (0.88)	4.37 (0.81)	-
		Combined	−1.81 (0.52)	1.27 (0.46)	-

negative values indicate deviation to left

*left and right hand indicates hand used; **mean (SE)

Table 4.5 Normative values for LBT by age, % error (mean, SE)

		Hausmann et al 2003			Pulsipher et al 2009		
age group	Line position	n	Hand used		n	Hand used	
			Left Hand	Right Hand		Left Hand	Right Hand
8–9 years	Left	-	-	-	9	−1.01 (1.72)	−1.77 (1.18)
	Centre		-	-		−1.30 (1.47)	1.79 (1.46)
	Right		-	-		2.84 (2.01)	3.51 (1.89)
	Combined		-	-		0.18 (1.13)	1.18 (1.06)
10–12 years	Left	22	-3.04 (1.12)	-0.09 (0.96)	16	−4.88 (1.29)	−3.05 (0.89)
	Centre		-2.10 (0.81)	2.16 (0.93)		-2.35 (1.10)	0.75 (1.11)
	Right		-1.79 (1.08)	2.57 (1.08)		0.00 (1.51)	4.67 (1.41)
	Combined		-2.28 (0.73)	1.62 (0.67)		−2.41 (0.85)	0.79 (0.80)
13–15 years	Left	24	-2.72 (0.66)	-1.18 (0.62)	11	−7.14 (1.56)	−2.13 (1.07)
	Centre		-2.52 (0.55)	0.10 (0.81)		−2.15 (1.33)	3.05 (1.32)
	Right		-2.02 (0.71)	-0.57 (0.83)		−0.53 (1.82)	3.91 (1.71)
	Combined		-2.44 (0.48)	-0.48 (0.60)		−3.26 (1.02)	1.61 (0.96)
16–18 years	Left	-	-	-	10	−3.97 (1.63)	−2.67 (1.12)
	Centre		-	-		−1.43 (1.39)	2.79 (1.39)
	Right		-	-		2.32 (1.91)	5.18 (1.79)
	Combined		-	-		−1.03 (1.07)	1.76 (1.01)
18–21 years	Left	25	-2.68 (0.78)	-1.41 (0.68)	-	-	-
	Centre		-2.16 (0.72)	-0.89 (0.46)		-	-
	Right		-1.04 (0.82)	1.55 (0.76)		-	-
	Combined		-1.98 (0.66)	-0.33 (0.48)		-	-
24–53 years	Left	27	-3.18 (0.62)	-1.34 (0.50)	-	-	-
	Centre		-2.32 (0.57)	-0.65 (0.38)		-	-
	Right		-1.33 (0.54)	-0.29 (0.68)		-	-
	Combined		-2.28 (0.51)	-0.74 (0.39)		-	-

negative values indicate deviation to left

Age is a key factor in LBT performance. There have been consistent reports that the typical leftward deviation which characterises pseudo-neglect tends to reduce and even reverse in direction to the right with increasing age in older adults [45, 58].

However, testing in children has produced contrasting results. Classically, younger children are thought to deviate from true centre according to the hand used such that they tend to have a left response bias when using the left hand and a right bias for the right hand. As they develop, their responses progressively move towards the pseudo-neglect seen in adults where they deviate to the left regardless of which hand is used. More recent studies have questioned this with results revealing considerable variation both in the directional bias and the magnitude of the deviation from true centre across different age groups [48].

Table 4.6 Factors that influence line bisection test

Factor	Effect
Age	Deviation progressively shifts rightward with increasing age in adults
Sex	No effect
Handedness	Right handers greater deviation to the left than Left handers
Reading direction	Leftward deviation in left-to-right readers (e.g. English) v rightward deviation in right-to-left readers (e.g. Hebrew)
Hand used	Greater deviation to the left when using Left hand vs Right hand, especially for Right handers
Scanning direction	Greater left deviation when scanning from left-to-right vs right-to-left
Gaze direction	Leftward deviation with gazing to left v rightward deviation with gazing to right
Line position	Greater left deviation when line positioned to left of midline of paper/screen Greater left deviation when paper/screen containing line is presented in left hemispace vs right hemispace
Line length	Greater deviation to left with longer line lengths

Other factors that have subsequently been identified as relevant to LBT performance include viewing distance. For example, a progressive shift from a leftward to a rightward bias has been reported as the distance between the participant and the line was increased from 30cm to 150cm (i.e. going from near to far-space) [52, 59]. Numerous interactions between these different variables have also been investigated with varying effects on LBT (e.g. [53, 60]).

It is clear from these reports that these factors need to be taken into account when conducting the LBT and in comparing results with previous findings.

4.4 Proprioception

Proprioception refers to the ability to perceive the posture of one's body in external space and the position of different body parts relative to each other. As such, it is essential in constructing up-to-date body representations such as body schema.

Unlike other properties of body schema described in this chapter, proprioception has been tested previously in AIS as described in the systematic review in Chapter 3, both in terms of joint angle reproduction and movement detection threshold (MDT). To date, evaluation of

MDT has not been undertaken in the trunk in AIS. This is partly due to practical difficulties in being able to conduct testing using passive movement in this region. MDT testing also requires specialised equipment that makes it unfeasible to conduct outside of a specialist centre. In contrast, position matching methodologies do not require such sophisticated equipment and can be easily performed in a clinical setting. They are also able to test joint position sense in areas of the body that are more difficult for MDT testing such as the trunk and spine.

4.4.1 Position matching

Position matching evaluates the ability of a subject to be able to match a previously determined target position. This is performed whilst blindfolded to remove visual cues. The closer they are able to reproduce the target position, the more accurate they are. The difference between the actual and the perceived target position is described as the repositioning error.

4.4.1.1 Normative values

Position matching ability in the trunk or spine has not been evaluated in people with AIS although it has been evaluated in adult scoliosis. Bissolotti et al [64] reported mean absolute repositioning errors of 3.4 degrees (SD 1.5) during sideflexion in 40 people with adult scoliosis (10 M, mean age 61.8yrs SD 11.5). Unfortunately, few details were provided as to the testing procedures and measurement tools used.

Testing of position matching has also been conducted extensively in the lumbar spine of healthy non-scoliotic people, usually in comparison with LBP patients. These include studies evaluating repositioning error in lumbar flexion [65-77], sideflexion [67, 68, 70, 71, 74, 75, 77] and rotation [71, 74, 75, 78], with absolute errors ranging from 1.6 degrees to 5.2 degrees depending on direction of movement (Table 4.7). A further study calculated overall repositioning error involving all directions of movement [72]. In general, testing in rotation and sideflexion appear to involve less absolute error than flexion. The variation in results reported by these trials are most likely due to differences in test protocols, measurement equipment and subjects. Note that only trials involving gross spinal movement and that measured angular displacement (degrees) were included in Table 4.7. Those that investigated pelvic tilt or specific spinal curves in isolation were not included.

4.4.1.2 Measurement properties

Test-retest reliability in the trunk has been investigated by a number of authors (Table 4.8) [65, 67, 70]. Due to the large variations in the reported ICC figures (and the lack of reporting of 95% CI in some studies), it is unclear as to how reliable testing is. Some of the reported confidence intervals are very low suggesting poor reliability. It would appear that, in general, testing of position matching with spinal rotation is the most reliable followed by flexion. The differences reported are most likely due to the differences in testing procedures and measurement tools.

Various factors have been reported to affect position matching ability. A number of studies have reported reduced error when repositioning is done through active rather than passive movement [74, 78]. It is presumed that greater sensory feedback from muscle contraction contributes to the greater accuracy in active movement. There are some reports that the position in which testing is conducted can also affect performance. Sitting has been reported as involving greater repositioning error than standing [72], possibly due to reduced movement occurring in the lower limbs, and therefore reduced proprioceptive feedback.

There is some uncertainty regarding the effect of where the target position is within the overall range of movement (i.e., how far the subject has to move) on repositioning error with some studies describing greater accuracy with smaller movements [73, 79], and others reporting no effect [66, 68, 69, 80] or even greater accuracy with larger movements [81]. There is also some doubt as to the effect of movement direction with some reports of an effect on repositioning error [82], while others report no effect [69]. For testing involving side-bending or rotation tests, no significant differences between right and left side positioning accuracies were found [83].

Table 4.7 Position matching in healthy controls - absolute error

study	group	n	Target position	Absolute error,degrees (mean, SD)		
				Flexion	Sideflexion	Rotation
Gill & Callaghan 1998	Healthy controls	20 (7M, mean age 32.9yrs, range 24-53)	20 deg	4.45 (3.41)	-	-
Swinkels & Dolan 1998	Healthy controls	20 (12M, mean age 33.6yrs range 23-52)	50% max ROM	4.35 (3.90)	2.23 (2.24)	-
McNair & Heine 1999	Healthy controls	40 (20M, mean age 26.3yrs SD 6)	random throughout ROM	3.62 (1.7)	-	-
Swinkels & Dolan 2000	Healthy controls	20 (8M, mean age 30.6yrs range 23-44)	33, 50 & 66% max ROM	3.50 (2.35) / 4.34 (2.50) / 4.14 (2.25)	1.84 (1.47) / 1.86 (1.43) / 1.87 (1.40)	-
Newcomer et al 2000*	LBP	20 (8M, mean age 39.3yrs SD 11.4)	50% max ROM	2.4	-	-
	Healthy controls	20 (7M, mean age 39.1yrs SD 11.3)				
Koumantakis et al 2002	Healthy controls	18 (8M, mean age 24.6yrs SD 4.0)	flexion 20 deg / sideflexion 15 deg	3.46 (2.04)	2.36 (1.36)	-
Feipel et al 2003	Healthy controls	21 (16M, mean age 40yrs SD 10)	50% max ROM	4.5 (3.9)	2.1 (2.6)	1.6 (1.5)
Preuss et al 2003**	Healthy controls	70 (70M, mean age 34.5yrs SD 8.7)	return to neutral from max ROM: sitting / standing	3.6 (2.3) / 2.5 (1.2)	-	-
Descarreaux et al 2005*	Healthy controls	15 (9M, mean age 38.2yrs SD 10.7)	15, 30 & 60 deg	2.13 (0.23) / 2.82 (0.27) / 5.20 (0.62)	-	-
	LBP	16 (11M, mean age 41.1 yrs SD 11.37)				
Silfies et al 2007	Healthy controls	232 (117M, mean age 19.3yrs SD 1.3)	Return to neutral from 20 deg	-	-	1.6 (0.8)
Lee et al 2010	Healthy controls	24 (14M, mean age 42.4yrs SD 9.0)	Return to neutral from 15 deg	2.3 (1.3)	1.8 (0.9)	1.7 (0.9)
Tsai et al 2010	Healthy controls	16 (16M, mean age 47.9yrs SD 8.3)	80% max ROM	2.1 (0.9)	1.65 (0.61)	2.35 (0.77)
Georgy 2011	Healthy controls	15 (mean age 38.5yrs SD 5.85)	30 deg	2.8 (0.94)	-	-
Gong 2014	Healthy controls	30 (2M, mean age 22.45yrs SD 0.52)	flexion 35 deg / sideflexion 30 deg	1.83 (1.28)	1.72 (1.26)	-

* combined results as no statistically significant difference between groups

** overall mean repositioning error from flexion, sideflexion L & R, rotation L & R tests

Table 4.8 Test-retest reliability of trunk position matching ability

study	group	interval between tests	Intraclass Correlation Coefficient (95% CI)		
			Flexion	Sideflexion	Rotation
Gill & Callaghan 1998	LBP (n=5); Control (n=5)	12 weeks	0.852	-	-
Koumantakis et al 2002	LBP (n=62)	minimum 5 days	0.41 (0.02-0.64)	L: 0.24 (0-0.54) / R: 0.42 (0.04-0.65)	L: 0.51 (0.17-0.71) / R: 0.58 (0.29-0.75)
	Control (n=18)	3 sessions with 1 week between each	0.76 (0.47-0.90)	L: 0.48 (0-0.79) / R: 0.22 (0-0.68)	L: 0.80 (0.57-0.92) / R: 0.76 (0.48-0.90)
Swinkels & Dolan 1998	Control (n=20)	2 weeks	0.790 - 0.898	L: 0.339-0.709 / R: 0.428-0.682	-

Most studies have reported no differences in repositioning error in the trunk according to age or gender [65, 69-71]. These studies did not specifically investigate position matching ability in older adults. In contrast, repositioning error was increased in older adults in testing of the cervical spine [84], the upper limb [85] and the knee [86-88].

Changes in trunk positioning accuracy have been reported with age in children and adolescents [89]. Healthy school children (n=253, 132 M) between the ages of 7-18 years were asked to return to a neutral (reference) standing position following trunk side flexion to the left or right. Repositioning error was calculated between the perceived and reference position and expressed in degrees. Accuracy was reported as improving with increased age (7 years: mean absolute error 2.5 deg SD 1.1; 18 years: 0.9 deg SD 0.6). Interestingly, they noted a relative decrease in positioning accuracy between the ages of 11-15 years, a period that corresponds with the adolescent growth spurt. Accuracy increases again after this period with the authors suggesting that trunk proprioception reaches adult levels of accuracy at approximately 15-16 years of age.

4.5 Summary

In summary, there are a number of different properties thought to be associated with body schema. These include tactile acuity, laterality discrimination, spatial perception and proprioception.

A number of tests have been utilised in evaluating these properties in chronic pain conditions. These include TPDT, localisation, left/right judgement, LBT and position matching. They have

generally involved equipment and procedures that are practical to use in a clinical setting rather than a lab-type environment, which is consistent with the type of studies that form the basis of this thesis. None have been used previously in testing people with AIS apart from proprioceptive testing, although this involved the knee and elbow rather than the spine.

Where possible normative data and psychometric properties have been presented. Because this is a relatively new area of investigation, there are few studies that have investigated this in any great detail. It is only recently that research has been conducted in this direction which has provided sufficient information to inform test selection and interpretation, including identifying factors that need to be taken into account when conducting these tests.

The next chapter will go on to describe the methods used in the first of the studies which form part of this thesis examining body schema in AIS.

5 Research question 1 - case control study (methods)

This chapter describes the methodology used in the case-control study conducted as part of this thesis. A brief overview of the research question the study is addressing is provided initially. The rest of this chapter then focuses specifically on the case-control methods with the results described in chapter 5.

Reporting in this and subsequent chapters is in accordance with the STROBE guidelines for the reporting of observational studies [1, 2].

5.1 Overview

5.1.1 Research question

The research questions that this thesis is seeking to answer are listed below (Table 5.1). The initial study is concerned with answering the first of these questions.

Table 5.1 Research question - Case control study

Research questions	
1	**do adolescents with AIS (cases) differ from non-scoliotic adolescents (controls) with regard to mechanisms that are thought to underpin body schema?**
2	in adolescents with AIS, is there any relationship between the mechanisms thought to underpin body schema and the magnitude of spinal deformity?
3	is there any relationship between changes in body schema and progression of the spinal deformity in AIS over time?

5.1.2 Hypothesis tested

The hypothesis derived from the above question is that:

> H_1: *adolescents with AIS differ from non-scoliotic controls with regard to mechanisms that are thought to underpin body schema*

The null hypothesis (H_o) is that there are no differences in underlying mechanisms of body schema between adolescents with or without AIS.

5.1.3 Study outline

To test this hypothesis, a case control comparison of body schema between AIS patients and controls was conducted. Data for cases was obtained from participants with AIS during a recent NIHR-funded feasibility study with which this PhD project was linked [3]. Although nested within the feasibility study, this doctoral project addressed distinct outcomes over a longer time-frame (i.e. 12 months rather than 6 months). Data from control participants was collected separately as part of this doctoral project.

5.2 Methods - case control study

5.2.1 Study design

As described previously in Chapter 1, AIS is relatively rare therefore studies that attempt to determine differences between people with AIS and those without need to take this into account. A traditional cohort study would be impractical due to the time required to recruit sufficient people with AIS. For this reason, a case-control design was used. In contrast to typical case-control studies, this study used a cross sectional approach by recruiting participants prospectively and making observations at one time point only.

5.2.2 Setting

Cases were recruited from spinal and/or scoliosis clinics at 4 NHS specialist centres in the UK (Royal Orthopaedic Hospital, Solihull; Nuffield Orthopaedic Centre, Oxford; Frenchay Hospital, Bristol; James Cook University Hospital, Middlesbrough) as part of the NIHR-funded feasibility study described previously [3]. The centres were amongst 35 listed by Scoliosis Association UK (SAUK) and the British Scoliosis Research Foundation as having clinicians actively managing and performing surgery for patients with scoliosis. Recruitment took place between December 2012 and October 2013.

Control participants were sourced from schools. The advantage of using schools is that there is a large group of potential participants neatly divided into groups by age. Students are likely to be representative of the population from which cases are drawn, thereby reducing the chance of selection bias [4]. They are also more than likely to be well and therefore unlikely to suffer from conditions that would result in exclusion, or from other conditions that may act as confounders. Sourcing controls from hospitals runs the risk of including participants whose

condition has an effect on the outcome measures. The disadvantage of using schools is the potential difficulty in gaining permission from head-teachers to approach their students. Also, school students are less likely to be motivated to participate in a study which is not seen to be directly relevant to them. The reduced level of uptake amongst students is balanced to some extent by the large pool of potential recruits.

Where possible it is preferable to source controls from the same geographical area as cases [4]. Therefore, schools in Coventry, Warwickshire and Oxfordshire were approached as sources of recruitment for control participants as these regions fall within the catchment of two of the hospitals from which cases were recruited. It should be noted that the hospitals themselves were specialist scoliosis centres which treat patients from a wide area and therefore, potential case participants do not necessarily live in close proximity to the hospitals. Recruitment of controls took place between October 2014 and February 2016.

5.2.3 Participants

5.2.3.1 Cases

Only patients with a diagnosis of AIS made by an orthopaedic consultant specialising in scoliosis and confirmed by medical imaging (x-ray or MRI) were asked to participate. The inclusion criteria for cases were:

- age 10-16 yrs old
- a diagnosis of mild to moderate AIS (i.e. a Cobb angle between 10 - 50 degrees assessed radiographically).

Exclusion criteria were:

- Cobb angle <10 degrees or >50 degrees
- previous spinal surgery or on waiting list for spinal surgery within next 12 months
- non-idiopathic scoliosis (e.g. congenital malformations, syringomyelia, neurofibromatosis, spina bifida)

A curvature of at least 10 degrees is necessary for a diagnosis of AIS, therefore any deformity less than this threshold was excluded. Severe scoliosis (i.e. Cobb angle > 50^{o}) is usually managed surgically, therefore patients with curves greater than this threshold were also excluded. Non-idiopathic scoliosis generally involves some form of neurological or developmental problem that may have a confounding effect on the properties of body schema that were tested in this study, hence people with these problems were not included. Conservative treatments potentially received by participants in the past, including bracing and exercise, did not form part of the exclusion criteria. Neither of these are commonly utilised in the UK.

Potential participants were initially approached by clinicians supported by trained research staff (nurses or physiotherapists). The screening and recruitment systems were tailored to individual sites. In some sites, research clinicians would be present in clinic and discuss the study with patients. At others, clinicians would perform the screening and pass details to the research clinicians to contact patients and families at a later date. At one site (JCUH), a specialist nurse used hospital records of patients who were due to attend a new patient or review clinic appointment and approached patients who appeared to be potentially eligible. At all centres, interested patients were provided with written information about the study (Appendix 2). If they were interested and willing to participate, they were booked in for a designated research clinic appointment with a research clinician where eligibility was confirmed, formal consent taken (Appendix 4) and baseline questionnaires and physical measures completed (Appendices 5, 7-20). Consent was obtained by trained research clinicians following Medical Research Council guidelines [5] and was provided by the child where capable or the parents/carers. Regardless of who provided consent, agreement (or assent) to participate was required from both the child and the parents/carers to ensure all parties were willing to be involved.

5.2.3.2 Controls

Head teachers of all secondary schools in Coventry, Warwickshire and Oxfordshire, and all primary schools in Coventry (192 schools in total) with students of eligible age were contacted by letter, email or both for permission to approach students and invite them to participate. At schools which gave permission, students of relevant class years were given written information about the study (Appendix 3) along with an eligibility checklist and consent form to take home

and discuss with parents (Appendix 4.4). Consent/assent was obtained according to the same principles as for case participants. Those that returned forms were then checked to see if they matched with any of the controls according to age and sex. Participants who met the eligibility criteria and that were able to be matched were then asked to complete questionnaires at home and to attend a research appointment where eligibility was confirmed, questionnaires were checked for completeness and physical measures taken (Appendices 6, 8-19).

Inclusion criteria for the control group were:

- age 10-16 years
- matched according to age (±3 months) and sex with a case participant

Exclusion criteria were:

- scoliosis (as determined by clinical testing)
- other spinal pathology or neurological condition.
- other condition/injury where unable to complete tests

Clinical testing for presence of spinal deformity (Adam's test [6] and observation of spine/posture) were included as part of the physical testing to exclude any potential cases of AIS or other spinal conditions. It was performed by a single physiotherapist (the author) with relevant spinal and musculoskeletal training and experience. Any potential participant with significant spinal or trunk asymmetry which may indicate the presence of scoliosis was excluded along with any other condition which may influence study outcomes or prevent their participation in physical testing (e.g. broken leg). When scoliosis was suspected, the child was advised that the findings were only preliminary and a letter sent to the parents/carers advising them to seek further investigation. Assessment by medical imaging to confirm non-scoliotic status was not possible due to ethical and practical considerations.

5.2.3.3 Matching

The aim was to match controls to cases in a ratio of between 2 to 4:1 using sex and age at baseline assessment as the matching variables. Greater numbers of controls per case has been

shown to increase the statistical power although the added benefit drops significantly after 4:1 [7].

These matching variables were chosen because of the different rates of physical and/or mental development occurring during adolescence between sexes as well as the large differences between age groups during this stage of rapid development [8-10]. AIS is also more prevalent amongst females [11]. Age of each control was restricted to the age of their matching case ± 3 months.

5.2.4 Variables

Information collected from participants for the case-control analysis is listed in Table 5.2 and Table 5.3. These can be broken down into 3 broad categories of:

- demographics
- self-reported function, health-related quality of life (HRQoL) and body awareness/perception
- physical measures related to body schema

Note that the measures listed only include those relevant to the case-control study, i.e. all those collected from controls and a subset of measures from cases. Copies of all measures are provided in appendices 5 to 20.

Other data that were also collected from cases as part of the cohort study are listed separately in the relevant chapters that follow.

Table 5.2 Variables - self-report questionnaires & physical measures of body schema

	Domain	Instrument / test	data type	units / range	Cases / controls
Demographics	Age*	Participant reported	continuous	months	both
	Sex*	Participant reported	categorical (binary)	Female/Male	
	Ethnic group	Participant reported	categorical		
	Handedness	Edinburgh Hand Inventory (EHI)	categorical	Left/Right/Mixed	
	Pubescent status	Onset of puberty - participant reported	categorical (binary)	Yes/No	
		Age of occurrence - participant reported	continuous	years	
	Family history of scoliosis	Participant reported	categorical (binary)	Yes/No	
	Family income	Postcode income estimate	continuous	£	
		Parent income - participant reported	categorical		
	Height, weight, BMI	Standing height (m)	continuous	m	
		Weight (kg)	continuous	kg	
Scoliosis characteristics	Curve type	X-ray	categorical	Single/Double/Triple	cases
	Curve direction¥		categorical (binary)	Left/Right	
	Cobb angle¥		continuous	degrees	
	Curve location¥		categorical	thoracic/thoracolumbar/lumbar	
	Coronal balance		continuous	mm	
	Sagittal balance		continuous	mm	
	Risser sign		categorical	0 to 5	
	Treatments received	Current bracing status - participant reported	categorical (binary)	Yes/No	
		Previous exercise treatments received - participant reported	categorical		
	Duration of condition	Age at diagnosis - participant reported	continuous	years	

* matching variables

¥ primary curve

Table 5.3 Variables - self-report questionnaires & physical measures of body schema

	Domain	Instrument / test	data type	units / range	Cases / controls
Function, QoL, body awareness	Perceived spinal deformity	Spinal Appearance Questionnaire (SAQ-14) total	continuous	14 (best) to 70 (worst)	both
		appearance	continuous	10 (best) to 50 (worst)	
		expectations	continuous	4 (best) to 20 (worst)	
	Scoliosis-specific HRQoL	Scoliosis Research Society Questionnaire (SRS-22) total*	continuous	1 (worst) to 5 (best)	
		function	continuous	1 (worst) to 5 (best)	
		self image	continuous	1 (worst) to 5 (best)	
		pain	continuous	1 (worst) to 5 (best)	
		mental health	continuous	1 (worst) to 5 (best)	
	Generic HRQoL	EQ5D - 3L			
		mobility	categorical		
		self-care	categorical		
		usual activities	categorical		
		pain/discomfort	categorical		
		anxiety/depresssion	categorical		
		Health Status	continuous	0 (worst) to 100 (best)	
	Generic function	Paediatric Outcomes Data Collection Instrument (PODCI)¥	continuous	1 (worst) to 100 (best)	
		upper extremity & physical function	continuous	1 (worst) to 100 (best)	
		transfers & basic mobility	continuous	1 (worst) to 100 (best)	
		sports & physical functioning	continuous	1 (worst) to 100 (best)	
		comfort/pain	continuous	1 (worst) to 100 (best)	
		global function	continuous	1 (worst) to 100 (best)	
		happiness with physical condition	continuous	1 (worst) to 100 (best)	
	Body awareness	Kinaesthetic & Proprioceptive Awareness Questionnaire (KPAQ)	continuous	12 (worst) to 60 (best)	
Physical measures	Balance	Dynamic standing balance	continuous	seconds	both
	Spatial perception	Line bisection test	continuous	mm (converted to relative error, %)	
	Left / right awareness	Laterality discrimination accuracy - back & hands	continuous	% correct	
		Laterality discrimination reaction time - back & hands	continuous	msec	
	Tactile acuity	Two point discrimination	continuous	mm	
		Localisation	continuous	% correct	
	Trunk proprioception	Position matching - side flexion	continuous	degrees (converted to relative error, %)	

* questions related to treatment not included as part of case-control analysis

¥ questions related to expectations following treatment not included as part of case-control analysis

5.2.5 Demographics

Age, sex, ethnicity, handedness, puberty status, family income, family history of scoliosis, and height/weight were collected as part of demographic data (Appendices 5 and 6).

5.2.5.1 Handedness

Handedness was calculated using a modified version of the Edinburgh Hand Inventory (EHI). Subjects are asked to state which hand they routinely use for 8 different tasks (section 2, Appendices 5 and 6). Each item is scored from -50 (always left) to +50 (always right) and subjects are then assigned to categories of principally right- handed, left handed or mixed based on the total score [12].

5.2.5.2 Income

Gross weekly income figures were derived from postcodes and corresponding ONS estimates of average weekly household income for middle layer super output areas (MSOAs) in England and Wales. MSOAs are geographical regions consisting of between 2000 to 6000 households (5000 to 15000 people). These estimates provide the average household income for small areas within England and Wales, i.e. the income a household receives from wages and salaries, self-employment, benefits, pensions, plus any other sources of income [13].

5.2.5.3 Body mass index (BMI)

BMI was calculated from height (m) and weight (kg) using the following formula [14]:

$$BMI = weight / height^2$$

5.2.5.4 Radiological imaging

X-ray information for cases from the most recent radiographic assessment was also collected from hospital records to give an overview of the type and severity of the spinal deformities involved (Appendix 6). Case participants did not undergo additional x-rays as part of this study.

5.2.6 Self-report questionnaires

All self-report questionnaires used in the case control study, along with scoring instructions, are contained Appendices 8 to 12.

5.2.6.1 Perceived trunk symmetry/spinal deformity

There are a number of instruments available that address the concept of self-image. However, these tend to measure self-image as an overall concept. Very few have focussed specifically on perceptions of the trunk/spinal region, especially with regard to examining perceived symmetry or deformity which is of particular interest to people with scoliosis. Measures that have been developed include the Spinal Appearance Questionnaire (SAQ), Walter-Reed Visual Assessment Scale (WRVAS), on which the SAQ was initially based, and the Trunk Appearance Perception Scale (TAPS). The WRVAS has been reported to have a number of deficiencies, including lack of validity and problems with understandability by younger age groups [15], which is why the SAQ was developed. TAPS is similar to the SAQ although it has fewer items and does not measure expectations regarding trunk shape/symmetry. It has not been used as widely in scoliosis research and therefore, there is less information regarding its psychometric properties in comparison with the SAQ [15].

5.2.6.2 Spinal Appearance Questionnaire (SAQ-14)

The SAQ-14 is a self-report measure of perceived self-image (specifically, spinal/trunk symmetry). It was originally developed from the WRVAS and has undergone several iterations before arriving at the current 14 item questionnaire (Appendix 8) [15].

The SAQ consists of two scales (appearance and expectations) and uses a 5 point Likert-style scoring system [16, 17]. The appearance scale consists of 10 separate items. Each item relates to a specific component of trunk/spinal symmetry and displays a series of 5 images of increasing asymmetry/deformity. Participants are asked to choose the image which they believe they resemble the most. Scoring ranges from 1 to 5 for each item giving a total score for the scale of 10 (best) to 50 (worst).

The expectations scale is a series of four statements related to expectations or desires regarding trunk/spinal symmetry. Participants are asked to rate how well each statement applies to them (1-not true to 5-very true). Total score for the scale ranges from 4 (best) to 20 (worst).

Combining the appearance and expectations scales produces an overall total score ranging from 14 (best) to 70 (worst).

Psychometric properties of the current 14 item version of the SAQ were first evaluated in 1,802 North American adolescents with AIS who were undergoing either monitoring only, bracing, or were listed for surgical correction (mean Cobb angle 55.8^{o}; SD 13.7^{o}; range 0 to 123^{o}). The subscales and total score were reported as having good to excellent test-retest reliability and high internal consistency (Table 5.4) suggesting that it is reproducible and that, within each domain, individual items appear to measure the same construct [16]. A later study in 80 Spanish participants with IS (mean Cobb angle 45.9^{o}; range 25.1 to 77.2^{o}) produced very similar results [18].

No floor or ceiling effects were reported for the appearance and total scores. However, the expectations scale demonstrated significant ceiling effect with over a 1/3 of participants scoring the maximum (i.e. with greatest desire for change in trunk symmetry) [16].

Evaluation of convergent validity has produced differing results when comparing SAQ scores with curve magnitude and SRS22 self-image scores (Table 5.5). It is unclear as to why such differences exist between the two studies although the Spanish cohort included a wider age range with a mean age approximately 6 years older (mean 20.3 years, range 10-40 years) than the North American cohort (14.8 years, SD 2.1). It also included participants with other forms of IS rather than specifically AIS. Respondents in the Spanish study completed the questionnaire without any assistance whereas parental help was *"neither encouraged nor discouraged"* for the North American cohort.

Assessment of divergent validity also produced contrasting results between the two studies (Table 5.6). Again, the Spanish study reported greater correlations than the North American cohort which makes evaluation of overall construct validity difficult.

The SAQ appears to be able to discriminate between surgical and non-surgical candidates with Carreon et al [16] reporting statistically significant differences in SAQ scores between participants who were under observation or braced and surgical candidates ($p \leq 0.002$). Similarly, Matamalas et al [18] reported that SAQ appearance and total scores were able to discriminate between participants with Cobb angles ≥45^{o} and those with Cobb angles <45^{o} (Table 5.7). This threshold is often the point at which surgical treatment is recommended.

Responsiveness to change of the SAQ was evaluated in a separate study amongst a retrospective cohort of 126 AIS participants (mean age 14.9 years; SD 2.0 yrs; mean pre-op

Cobb angle 53.7°; SD 12.8; range 40 to 95°) who underwent surgical correction of the spinal deformity. Pre-operative scores were compared to scores 2 years post-surgery (Table 5.8) with statistically significant differences reported for both scale and total scores. The large effect sizes and standardised response means also indicate that the SAQ appearance and expectation scales, as well as the SAQ total score, are highly sensitive to change following surgery [17]. No testing of SAQ responsiveness has been performed in AIS patients with lesser initial Cobb angles or undergoing more conservative forms of treatment.

Table 5.4 Reliability & internal consistency SAQ

Property	study	SAQ appearance	SAQ expectations	SAQ total score
Test-retest reliability	Carreron et al 2011	0.81	0.91	0.89
Cronbach's α	Carreron et al 2011	0.89	0.88	0.88
	Matamalas et al 2014	0.89	0.87	0.88

Table 5.5 Convergent validity - SAQ versus curve magnitude and SRS-22

property	variable	study	SAQ appearance	SAQ expectations	SAQ total score
correlation, r	Cobb angle	Carreon et al 2011	0.361*	0.148	-0.324*
		Matamalas et al 2014	0.61*	0.24*	0.55*
	SRS22 self-image	Carreon et al 2011	-0.393*	-0.324*	-0.438*
		Matamalas et al 2014	-0.67*	-0.55*	-

* statistically significant

Table 5.6 Divergent validity - SAQ versus other SRS-22 scales

property	variable	study	SAQ appearance	SAQ expectations	SAQ total score
correlation, r	SRS22 pain	Carreon et al 2011	-0.193	-0.117	-0.191
		Matamalas et al 2014	-0.49*	-0.24*	-
	SRS22 function	Carreon et al 2011	-0.239	-0.09	-0.217
		Matamalas et al 2014	-0.60*	-0.29*	-
	SRS22 mental health	Carreon et al 2011	-0.151	-0.093	-0.153
		Matamalas et al 2014	-0.43*	-0.2	-
	SRS22 total score	Carreon et al 2011	-0.332	-0.205	-0.335
		Matamalas et al 2014	-	-	-

* statistically significant; NB: p-values for Carreon et al not reported

Table 5.7 Discriminant validity - Mean (SD) SAQ score by group

study	group	mean Cobb angle (SD or range)	SAQ appearance	SAQ expectations	SAQ total score
Carreron et al 2011	observed	24.48 (7.57)	15.88 (3.13)	8.78 (4.78)	24.66 (6.47)
	braced	29.42 (11.97)	16.17 (3.33)	11.33 (5.63)	27.50 (7.57)
	surgical	56.42 (12.97)	25.16 (3.33)**	15.89 (4.6)**	40.91 (9.22)**
Matamalas et al 2014	Cobb < 45°	35.2 (25.1-44.2)	20.33 (5.6)	14.50 (5.2)	34.80 (9.3)
	Cobb ≥ 45°	56.6 (45-77.2)	28.18 (6.7)*	16.20 (4.5)	44.30 (9.2)*
	combined	45.9 (25.1-77.2)	24.27 (5.0)	15.3 (7.3)	39.6 (14-61)

* statistically significant difference between groups <45° and ≥45°
** statistically significant difference between observed/braced and surgical groups

Table 5.8 Responsiveness to change following surgery - SAQ

SAQ scores	Cobb angle, °	SAQ appearance	SAQ expectations	SAQ total score
Pre-op	53.7 (12.8)	24.6 (6.0)	15.3 (4.9)	39.9 (9.1)
2yrs post-op	20.1 (10.5)	15.1 (4.5)*	8.2 (4.8)*	23.3 (7.9)*
effect size (Cohen's *d*)	*2.6*	1.7	1.5	1.8
Standardised response mean		1.4	1.2	1.5

* p<0.0001 difference in scores preop v postop; italics = effect size calculated by thesis author

In summary, despite some concerns with comprehension and interpretation in younger age-groups [19], the SAQ appears to have excellent test-retest reliability and internal consistency. It also appears to be able to discriminate between groups with differing severity of AIS by distinguishing surgical versus non-surgical candidates, and is sensitive to changes following surgical correction. There is some uncertainty as to construct validity, with contrasting results reported for convergent and divergent validity by the only two studies to have evaluated these properties. This may reflect age, curve and selection differences between the two cohorts.

No studies have evaluated the minimal clinically important difference (MCID) to date.

5.2.6.3 Health-related quality of life (HRQoL)

There are a wide variety of generic HRQoL instruments in use (e.g. SF-36, EQ5D). However, in the scoliosis literature, the Scoliosis Research Society questionnaire is used almost to the

exclusion of all other measures, and contains items that reflect issues that are of particular concern to people with scoliosis. The EQ5D was also included to provide a generic measure of HRQoL. It has the advantages of being widely used and understood, as well as being relatively concise.

(i) Scoliosis Research Society questionnaire (SRS-22r)

The SRS-22r is a disease-specific measure of HRQoL (Appendix 9). It consists of 22 items across 5 domains - function/activity, pain, self-image, mental health (5 items each) and satisfaction with treatment (2 items) [20]. The satisfaction with treatment scale was not used for the case-control analysis reducing the questionnaire to 20 items. Each item uses a 5 point Likert-style scoring system which is converted to give a score of between 1 (worst) to 5 (best) for each scale as well as for an overall summary (mean) score.

Psychometric testing has been conducted in both children and adults with AIS. Test-retest reliability has been reported as excellent in a group of adults who had previously undergone surgery for IS as adolescents [21]. The same study also described internal consistency as good to excellent for all the SRS-22r subscales. Similar results have been reported by other authors in both adults and younger age groups (Table 5.9) [18, 20, 22, 23].

Table 5.9 Reliability & internal consistency SRS-22r

property	test	study	function	self image	pain	mental health
Test-retest reliability	intra-class coefficient	Asher et al 2003a	0.90¥	0.9	0.96	0.87
Internal consistency	Cronbach's α	Asher et al 2003a	0.86¥	0.75	0.92	0.9
		Asher et al 2003b	0.61¥	0.71	0.86	0.85
		Asher et al 2006	0.78	0.77	0.85	0.82
		Lai et al 2010	0.83	0.8	0.87	0.9
		Matamalas et al 2014	-	0.78	-	-

¥ = using unrevised function scale

Convergent validity of the SRS-22r has been tested with Cobb angle and other self-report questionnaires (Table 5.10). Comparison with Cobb angle reveals some variability with studies

reporting correlations that suggest medium to large effects [18, 24] while others report weaker correlations [16].

Correlation of the SRS-22r self-image scale with the SAQ has been described in the previous section (Table 5.5) with medium to large associations reported [16, 18]. Even stronger relationships have been demonstrated with relevant scales of generic HRQoL instruments such as the SF-36 [21] and the Child Health Questionnaire (CHQ-CF 87) [25]. Medium to strong associations were also reported with the overall EQ5D index scores and health state visual analogue scale. The two pain scales demonstrated a moderate correlation as did the SRS-22r self-image scale with the EQ5D anxiety/depression score (r=0.49 and 0.42 respectively). Interestingly, only weak, non-statistically significant correlations were reported between the SRS-22r function scale and the EQ5D mobility and usual activity scales. There was a stronger association with the EQ5D self-care scale indicating that the two questionnaires may capture distinct aspects of function [26].

The SRS-22r has been reported to be able to discriminate between mild/moderate and more severe scoliosis as defined by Cobb angle and/or treatment group (i.e. surgical candidates versus non-surgical) [16, 18, 24, 27, 28]. However, it appears less able to distinguish between smaller intervals of curve magnitude [28] or non-scoliotic controls from scoliosis patients with smaller curves (Table 5.11) [24], possibly because smaller curves do not impact on quality of life.

Responsiveness to change of the SRS-22r following surgery to correct the spinal deformity has been evaluated although only a few authors have investigated this amongst adolescents (Table 5.11). Large changes in the self-image scale indicate that it is highly responsive following surgery and this appears to be the main driver of the responsiveness reported for the SRS-22r total score. Although significant differences were reported by some authors for other scales pre- and post-surgery, none of them demonstrated more than a small effect size [17, 22, 27, 29]. Interestingly, statistically significant differences were not reported for function following surgery by any of the studies. No study has looked at responsiveness to change following more conservative treatment options.

The MCID following spinal fusion in adolescents has been estimated for various subscales by two studies with reasonably consistent results (Table 5.12). The estimates indicate the change

in score necessary for the patient to notice a clinically significant change. Variations between the MCIDs reported by the two studies could be explained by different methodologies - Carreon et al [29] utilised the SRS-30 as the anchor for determining change, whereas Bago et al [30] compared change using a single item global change question (worse, same, better, much better). In both of these studies, only the MCID for the self-image scale was larger than the error (SEM) or minimal detectable difference (MDC). This indicates that for the other scales, changes greater than the calculated MCID would be required to differentiate them from measurement error. Again, no study has examined MCID following more conservative methods of treatment.

Table 5.10 Convergent validity SRS-22r

Pearson's r		function	self image	pain	mental health	total score	study
Cobb angle,°		-0.27¥*	-0.50*	-0.37*	-0.27*	-0.48*	Asher et al 2003c
		-	-0.198	-	-	-0.113*	Carreon et al 2011
		-	-0.41*	-	-	-	Matamalas et al 2014
SF-36	Role-physical	0.84¥*	-	0.79*	-	-	Asher et al 2003a
	Physical functioning	0.77¥*	0.68*	0.76*	-	-	
	Pain index	0.77¥*	-	0.92*	-	-	
	General health perceptions	0.69¥*	0.74*	-	-	-	
	Social functioning	-	0.69*	-	0.83*	-	
	Mental health index	-	-	-	0.90*	-	
	Vitality	-	-	-	0.72*	-	
CHQ-CF 87	Physical Function	0.73*	-	0.42*	-	-	Glattes et al 2007
	Family Activity	0.71*	-	0.45*	-	-	
	Role Physical	0.54*	-	-	-	-	
	General Health	0.52*	0.50*	0.41*	-	-	
	Bodily Pain	-	-	0.82*	-	-	
	Mental Health	-	0.48*	-	0.68*	-	
	Family Cohesion	-	0.47*	-	0.53*	-	
	Self-Esteem	-	0.50*	-	0.59*	-	
	Behaviour	-	-	-	0.63*	-	
EQ5D 3L	Mobility	-0.17	-	-	-	-	Adobor et al 2010
	Self-care	0.43*	-	-	-	-	
	Usual activities	-0.14	-	-	-	-	
	Pain	-	-	-0.49*	-	-	
	Anxiety/depression	-	-0.42*	-	-	-	
	EQ-5D summary score	0.36*	0.62*	0.59*	0.57*	0.67*	
	EQ-VAS	0.52*	0.44*	0.40*	0.35*	0.57*	

¥ = using unrevised function scale; * = statistically significant

Table 5.11 Discriminative ability & responsiveness to change following surgery SRS-22r

property	study	group	function	self image	pain	mental health	total score	Cobb angle, °
Discriminative ability (mean scores, SD)	Asher et al 2003c	suspected AIS	4.5 (0.35)¥	4.3 (0.59)	4.7 (0.44)	4.5 (0.48)	4.5 (0.35)	
		Non-surgical	4.4 (0.36)¥	4.2 (0.50)	4.6 (0.54)	4.4 (0.54)	4.4 (0.33)	
		surgical	4.2 (0.42)¥	3.4 (0.77)*	4.2 (0.75)*	4.0 (0.77)*	3.9 (0.54)*	
	Carreon et al 2011	observed	4.45 (0.29)	4.28 (0.58)	4.50 (0.48)	4.27 (0.53)	4.37 (0.40)	
		braced	4.60 (0.31)	4.09 (0.47)	4.78 (0.29)	4.27 (0.48)	4.41 (0.31)	
		surgical	4.12 (0.56)*	3.28 (0.66)*	4.09 (0.72)*	3.96 (0.68)*	3.84 (0.47)*	
	Berliner et al 2012	non-surgical Cobb < 20°	4.5 (0.47)	4.1 (0.44)	4.6 (0.58)	4.4 (0.56)	4.4 (0.36)	
		non-surgical Cobb 20-40°	4.4 (0.37)	4.0 (0.54)	4.6 (0.51)	4.2 (0.64)	4.3 (0.38)	
		surgical Cobb 41-50°	4.1 (0.69)	3.5 (0.59)*	4.1 (0.72)*	4.1 (0.58)	3.9 (0.48)*	
		surgical Cobb 51-60°	4.2 (0.54)	3.3 (0.58)*	4.3 (0.65)	4.0 (058)	3.9 (0.44)*	
		surgical Cobb > 60°	4.3 (0.55)	3.5 (0.57)*	4.1 (0.91)	4.0 (0.80)	4.0 (0.53)**	
	Matamalas et al 2014	Cobb < 45°	-	3.43 (0.6)	-	-	-	
		Cobb ≥ 45°	-	3.0 (0.8)*	-	-	-	
	Bastrom et al 2015	Cobb < 45°	4.6 (0.5)	4.1 (0.7)	4.2 (0.7)	4.0 (0.7)	4.0 (0.5)	
		Cobb ≥ 80°	4.2 (0.7)*	3.5 (0.7)*	3.8 (0.9)*	3.8 (0.7)*	3.7 (0.5)*	
Responsiveness (mean scores, SD)	Asher et al 2003b	pre-op	4.1 (0.58)¥	3.3 (0.67)	3.9 (0.93)	4.0 (0.70)	3.8 (0.58)	63 (range 40 to 137)
		2yrs post-op	4.3 (0.36)¥	4.1 (0.61)*	4.3 (0.68)*	4.3 (0.48)	4.3 (0.42)*	-
		Effect size (Cohen's *d)*	*0.3*¥	*1.2*	*0.4*	*0.4*	*0.9*	-
	Carreon et al 2010	pre-op	4.15 (0.55)	3.29 (0.64)	4.10 (0.71)	3.96 (0.69)	3.86 (0.46)	53 (18)
		1yr post-op	4.23 (0.46)	4.29 (0.58)*	4.35 (0.61)*	4.22 (0.64)*	4.30 (0.41)*	-
		Effect size (Cohen's d)	*0.1*	*1.6*	*0.4*	*0.3*	*1*	-
	Carreon et al 2013	Pre-op	4.2 (0.5)	3.4 (0.7)	4.3 (0.7)	4.1 (0.7)	3.9 (0.4)	53.7 (12.8)
		2yrs post-op	4.3 (0.4)	4.2 (0.6)*	4.4 (0.6)	4.3 (0.5)	4.3 (0.4)*	20.1 (10.5)
		Effect size (Cohen's d)	0	1.2	0.2	0.3	0.8	*2.6*
	Bastrom et al 2015 §	pre-op	4.5 (0.56)	3.4 (0.67)	4.1 (0.7)	4.0 (0.68)	3.9 (0.48)	55 (13)
		2yrs post-op	4.6 (0.48)	4.4 (0.56)	4.4 (0.62)	4.2 (0.67)	4.4 (0.46)	20 (9)
		Effect size (Cohen's d)	*0.2*	*1.5*	*0.4*	*0.3*	*1*	*2.7*

italics = effect sizes calculated by author for this thesis; ¥ = using unrevised function scale

* = statistically significant; § = p-values not reported

Table 5.12 MCID of SRS-22r

test	study	function	self image	pain	mental health	total score
ROC	Carreon et al 2010	0.08	0.98	0.2	-	-
	Bago et al 2009	0.0	1.6	0.2	0.4	0.4
AUC	Carreon et al 2010	0.65 (0.60–0.69)	0.63 (0.60–0.68)	0.72 (0.70–0.77)	-	-
	Bago et al 2009	0.65	0.69	0.69	0.61	0.71
SEM	Carreon et al 2010	0.17	0.21	0.15	-	-
	Bago et al 2009	0.29	0.18	0.22	0.14	0.18
MDC	Carreon et al 2010	0.41	0.47	0.33	-	-
	Bago et al 2009	0.8	0.5	0.6	0.4	0.5

ROC = receiver operating characteristic; AUC = area under the curve
SEM = standard error of measurement; MDC = minimum detectable change

In summary, the SRS-22r appears to have excellent reliability and internal consistency. Construct validity testing indicates that it has good convergence with other generic measures of HRQoL (e.g. SF36), though less so with the EQ5D and measures of curve deformity such as the Cobb angle. It is able to distinguish AIS patients with minor/moderate spinal deformities from those with more severe changes (as indicated by Cobb angle and/or treatment status) although it seems less sensitive to smaller differences between patients. Self-image appears to be the only factor that responds with clinical significance following surgery with calculated MCIDs indicating that a 1 to 1.6 change is required to indicate any meaningful change for the patient. This supports the findings reported in the previous section for the SAQ and suggests that improved self-image is an important outcome of surgery for people with AIS.

(ii) EQ-5D-3L

The EQ-5D-3L is a generic self-report HRQoL measure widely used across all health conditions (Appendix 10). It consists of 5 domains: mobility, self-care, usual activities, pain/discomfort and anxiety/depression. Each domain consists of 3 possible responses (no problems, some/moderate problems, severe/extreme problems). It also includes a measure of current health status using a visual analogue scale (VAS) ranging from 0 (worst imaginable health state) to 100 (best imaginable health state).

There is also a 5L version of the EQ-5D which contains 5 possible responses to each domain, therefore making it more sensitive and responsive to change. However, at the time the case

control study was conducted, no valuation set from which to derive utilities was available [31], an important component of the health economic analysis of the feasibility study with which this case control study was linked. The National Institute for Health and Care Excellence (NICE) have also recently published their concerns with the metrics and tariff values for the 5L version [31].

The psychometric properties of the EQ-5D-3L are well established across a number of different disease states although only limited evaluation has occurred in AIS. These limited reports suggest that it has good-to-excellent test-retest reliability and internal consistency (Table 5.13) [26]. It also has reasonable convergent validity with the SRS-22r as described in previous sections (see Table 5.10) although it does not appear to have any association with the most commonly used radiographic measures of spinal deformity either pre- or post-surgery (Table 5.14). Greater association was seen with the Posterior Trunk Symmetry Index (POTSI), a measure of surface trunk deformity and, therefore, more indicative of actual cosmetic, visible trunk changes than an internal radiographic measure [32, 33].

Discriminative ability, responsiveness and MCID have not been investigated for the EQ-5D in AIS to date.

Table 5.13 Reliability & internal consistency EQ-5D in AIS

property	test	overall index score	VAS health state
test-retest reliability	ICC	0.80 (0.68-0.88)	0.91 (0.85-0.95)
internal consistency	Cronbach's α	0.89 (0.81-0.94)	0.95 (0.92-0.97)

Table 5.14 Convergent validity EQ-5D with spinal deformity measures

Pearson's r	EQ5D score
Pre-operative Cobb	0.07
Post-operative Cobb	-0.10
POTSI	-0.54*

* statistically significant p<0.01

5.2.6.4 Generic function

(i) Paediatric Outcomes Data Collection Instrument (PODCI)

The PODCI is a generic self-report functional health outcomes measure designed for children and adolescents with orthopaedic conditions (Appendix 11) [34]. It consists of 53 individual items and is sub-divided into 7 sub-scales: upper extremity & physical function (8 items), transfers and basic mobility (11 items), sports and physical functioning (12 items), comfort/pain (3 items), global function (mean of the four previous scales), happiness with physical condition (5 items) and expectations of treatment (9 items). The expectations of treatment scale was not used for the case-control analysis. Standardised scores are calculated for each scale ranging from 0 (worst) to 100 (best).

Five items are not included in these scales - they relate to ill-health/energy levels during last week (2 items), school absence due to ill-health in last 12 months, ability to make friends, and satisfaction with current condition (1 item each).

In comparison with the SRS-22r, the PODCI has undergone very limited investigation of its psychometric properties. Those that have been performed have tended to focus on parent-completed rather than patient-reported versions. In accordance with its original purpose, these have encompassed a wide range of different conditions. To date, only one analysis of the patient-reported version of PODCI has been performed with subjects with AIS [35].

Test-retest reliability of the patient-report form was initially evaluated in children and adolescents suffering from a range of different orthopaedic and neuromuscular conditions, including AIS (n=30, age 2-18 yrs) [36], and subsequently in children/adolescents with juvenile idiopathic arthritis (JIA) (n=28, mean age 10.3yrs, SD 3.9) [37]. Despite using different analysis methods, both studies reported high levels of reliability, although the comfort/pain and happiness scales appeared to be less reliable in the JIA cohort (Table 5.15).

Similarly, internal consistency was also reported as excellent for the majority of scales by the two studies, again with happiness demonstrating less consistency (Table 5.15).

The same studies have assessed construct validity through comparisons with either physician-rated function or other HRQoL instruments and measures of disease activity (Table 5.16). Reported correlation figures between these and the various function-related subscales

indicates a strong relationship suggesting a reasonable degree of convergence. In contrast, the weak relationship between physician-rated function and the non-function PODCI scales (as illustrated by the low correlation figures for the comfort/pain and happiness scales) indicates satisfactory divergent validity. Note that for the multiple condition cohort, physician rated function was compared with the combined scores of parent and patient-completed forms [36].

Only one study has investigated the discriminative ability of the patient-completed PODCI in AIS (Table 5.17) [35]. Statistically significant differences were reported between AIS patients and non-scoliotic controls for the transfers/mobility, global function, sports/physical function and comfort/pain scales, with AIS patients recording lower scores (i.e. worse performance) particularly for the latter two scales (difference between means 10.8 and 11.5 respectively). Note that the controls for this comparison were from a separate study [38].

In contrast, the PODCI does not seem to be able to discriminate between AIS subjects with varying degrees of spinal deformity as evidenced by the lack of statistically significant differences between groups with increasing Cobb angles. Nor does it seem able to distinguish between AIS patients who have undergone surgery from non-surgical cases.

These results probably reflect 1) the relatively small sample sizes involved, 2) that the PODCI is a generic orthopaedic rather than an AIS-specific measure, and 3) that AIS does not usually involve major changes in function or other domains covered by the PODCI.

Table 5.15 Reliability - PODCI

property	test	study	upper extremity	transfers	sports	comfort / pain	global	happiness
test-retest reliability	Pearson's r	Daltroy et al 1998§	0.96	0.97	0.87	0.89	0.95	0.87
	ICC	do Monte et al 2013	0.97*	0.81*	0.97*	0.59*	-	0.53*
internal consistency	Cronbach's α	Daltroy et al 1998§	0.84	0.91	0.9	0.84	0.92	0.76
		do Monte et al 2013	-	-	-	-	0.82	-

* = statistically significant; § = no p-values provided

¥ = parent & adolescent-completed forms combined

Table 5.16 Construct validity PODCI

study	correlation with	upper extremity	transfers	sports	comfort / pain	global	happiness
Daltroy et al 1998[§]	physician rating global function[¥]	0.62 (0.40)	0.75 (0.67)	0.73 (0.70)	0.24 (0.23)	0.76 (0.68)	0.25 (0.20)
do Monte et al 2013	CHQ PF-28 physical function (Spearman's rho)	-	-	-	-	0.67*	-
	active joints (Spearman's rho)	-	-	-	-	-0.51*	-
	limited joints (Spearman's rho)	-	-	-	-	-0.56*	-

* = statistically significant; § = no p-values provided

¥ = parent & adolescent-completed forms combined; test-type not provided

Table 5.17 Discriminative ability of PODCI in AIS

group	n	upper extremity	transfers	sports	comfort / pain	global	happiness
normals[¥]	27	99.3 (1.6)	99.9 (0.6)	97.1 (3.8)	86.7 (14.5)	95.8 (3.8)	86.3 (12.5)
AIS	95	96.6 (7.6)	97.0 (5.4)*	86.3 (14.8)*	75.2 (22.4)*	88.8 (9.3)*	81.7 (18.1)
Cobb 10-29^{o}	23	98.6 (2.9)	98.7 (2.8)	80.2 (12.7)	74.3 (24)	90.5 (9.5)	83.5 (16.6)
Cobb 30-49^{o}	20	96.2 (5.1)	94.8 (7.7)	85.1 (16.1)	74.2 (17.5)	87.6 (9.4)	81.8 (17.9)
Cobb ≥50^{o}	4	96.0 (4.6)	97.0 (3.5)	89.5 (13.1)	64.8 (24.2)	86.8 (10.0)	65.0 (37.0)
surgery	46	95.8 (10.1)	97.0 (5.2)	84.2 (15.4)	76.8 (24.0)	88.4 (9.5)	82.1 (17.0)
no surgery	49	97.4 (4.1)	96.9 (5.6)	88.3 (14.0)	73.7 (20.9)	89.1 (9.3)	81.3 (19.3)

*= statistically significant difference between normals and AIS patients

¥ = from previous study Haynes & Sullivan 2001

In summary, the PODCI again appears to be a reliable instrument in AIS although more evidence is required to fully establish its validity. The currently available literature suggests it is not able to distinguish between cases based on severity of condition although there is limited evidence that it can discriminate between subjects with AIS and non-scoliotic controls. No assessment of responsiveness to treatment or calculation of the MCID has been performed to date for the PODCI in AIS.

5.2.6.5 Body awareness

Body awareness covers a range of different concepts. As part of this thesis, body awareness in relation to sensorimotor perception was of particular interest. For this reason, instruments designed to evaluate this aspect were considered for inclusion. The Body Awareness Questionnaire (BAQ) [39] and the Body Consciousness Questionnaire [40] focus on awareness of autonomic processes such as hunger and fatigue amongst other domains but do not specifically cover awareness of sensorimotor processes related to movement and posture. In contrast, the Kinaesthetic and Proprioceptive Awareness Questionnaire (KPAQ) is a body awareness questionnaire focussing on self-reported proprioceptive and kinaesthetic sensitivity. It specifically addresses the *"specific awareness and attribution of kinesthetic* [sic] *and proprioceptive cues from the body's limbs, muscles, etc"* [41].

(i) Kinaesthetic and Proprioceptive Awareness Questionnaire (KPAQ)

The KPAQ consists of 12-items and responses are given on a 5-point Likert scale which rates the accuracy of the statement for the subject (Appendix 12). Overall scores range from 12 (worst) to 60 (best).

The KPAQ is derived from an initial set of three questions proposed by Smith-Jackson [42]. Subsequent development occurred as part of a study exploring the relationships between psychosocial factors, biomechanical factors and musculoskeletal discomfort in the workplace [41].

Internal consistency was reported as good (Cronbach's α=0.82) and construct validity demonstrated in comparisons with the Body Awareness Questionnaire (Pearson's r=0.64, p<0.0001) [41]. The KPAQ has also demonstrated a strong correlation with trunk proprioception in adults during two small pilot studies [43, 44], suggesting that subjects have some awareness of their own proprioceptive ability. These results indicate some degree of convergent validity (Table 5.18).

As part of the original study using this instrument, KPAQ was evaluated against measures of musculoskeletal discomfort, coping style, anxiety and personality type, with low and non-significant correlations indicating divergent validity [41].

Table 5.18 Correlation between combined KPAQ/BAQ* score & trunk repositioning error

Type of movement	correlation, r	
	Kelaher et al 2003	Kelaher 2006
Flexion	-	-0.42
Lateral bending	-	-0.54
Axial rotation	-	-0.18
Mean score all 3 directions	-0.77	-0.67

* Body Awareness Questionnaire

Other aspects of psychometric testing (e.g. test-retest reliability, discriminative ability, responsiveness, MCID) have yet to be assessed. The KPAQ has not been used previously with children/adolescents or in AIS.

5.2.7 Physical measures of body schema

Physical measures of mechanisms thought to underpin body schema included evaluations of tactile acuity (two point discrimination and stimulus localisation), laterality discrimination (back and hands), proprioception (position matching), and spatial perception (line bisection test). These have been described in detail in Chapter 4 and further information regarding procedures, case report forms and scoring are described in appendices 14 to 19.

Data was also analysed taking into account the curve direction for cases and the corresponding side for the matched controls. This involved recoding each of the initial trials into affected (i.e. the direction of curve) and unaffected sides with respect to the side where testing was conducted. For example, for cases, if the curve was convex to the right, then data for the trial on the right side of the spine were reclassified as 'Affected side', and data from the left-side trial were classified as 'Unaffected side'. The reverse occurred for curves convex to the left. Controls adopted the same classification as their matched case.

5.2.8 Bias

The main sources of bias in an observational study are selection bias and information bias (e.g. misclassification, measurement error) [45]. Attempts were made to minimise selection bias through the use of standardised inclusion/exclusion criteria and participant recruitment procedures for both cases and controls (see section 5.2.3). The use of multiple recruitment

sites, and by recruiting both AIS and control participants from broadly similar regions, also aimed to reduce selection bias. However, those who agreed to participate in the study were self-selecting and it is impossible to determine the differences in any great detail between them and those who declined to participate, particularly for the control group. Full details of all those screened, recruited and followed up are described in the results section to enable estimation of potential selection bias.

Misclassification was minimised in case participants by ensuring scoliotic status was confirmed via medical imaging and specialist consultant review. In controls, a detailed physical examination of the spine and clinical testing was performed by an experienced clinician in an effort to ensure only non-scoliotic participants were included. However, the possibility exists that some controls might go on to develop AIS later on (especially younger age groups) or may have had changes too small to be noticed by clinical testing.

Attempts to reduce other forms of information bias included use of standardised outcome assessment methods and assessor training. Procedures were tested prior to recruitment and documented in a manual along with all other relevant study protocols. All personnel involved in participant assessment and measurement were provided with this manual and completed training to reduce the potential for measurement error. Subsequent visits by the author to observe assessment sessions ensured compliance with testing protocols.

Unfortunately, assessors were not able to be blinded to the status of the participant. However, different assessors for the case and control groups were used in an effort to minimise the potential for bias. Scoliosis participants may also respond differently to testing compared with control participants due to a heightened awareness of their trunk/spine rather than any 'true' difference. It is difficult to gauge how much of an impact this might have had.

Confounding variables are those that affect both the independent variable and the dependent variable [46]. Known confounders for AIS and measures of body schema include age, physical maturity (Risser sign) and, in some cases, sex. However, the possibility of an association being due to other unknown variables is also a known risk [47]. Attempts to minimise this were taken including matching the controls with AIS participants according to age, and sex, and; using multivariate analyses to account for potential confounders (e.g. curve type, Cobb angle).

5.2.9 Statistical analysis

Data analysis was performed using the IBM SPSS Statistics (version 22) software package. Categorical variables were summarised into frequency tables and chi-squared tests (or Fisher's exact test if count<5 in any category) performed where relevant to establish if observed values were significantly different from expected frequencies.

Descriptive statistics were calculated for all continuous variables along with plots to illustrate data distribution (histograms), medians and inter-quartile range (box plots), and means (with 95% confidence intervals). Independent t-tests were used to assess statistical significance of the difference between group means. In the case of non-correctable non-normal distributions, non-parametric tests (Mann Whitney U test) were used. Point-biserial correlations were conducted to determine if group-type was related to individual parameters. Effect sizes were calculated where relevant (Cohen's *d* or Pearson's r). Results were interpreted with regard to likely clinical significance.

Within-group analyses using paired samples t-tests (or non-parametric Wilcoxon signed-rank test) were also conducted to evaluate differences between left and right side and curve direction for cases (and corresponding side for matched controls. Analysis based on curve direction involved recoding each of the initial trials into affected (i.e. the direction of curve) and unaffected sides with respect to the side where testing was conducted. For example, for cases, if the curve was convex to the right, then data for the trial on the right side of the spine were reclassified as 'Affected side', and data from the left-side trial were classified as 'Unaffected side'. The reverse occurred for curves convex to the left. Controls adopted the same classification as their matched case.

5.2.10 Ethics

Ethics approval for collection of data from cases was provided by NRES (East of England - Cambridge South, 12/EE/0331) and the R&D departments of the NHS trusts involved. Approval from University of Warwick BSREC (REGO-2013-590) enabled collection of data from the control participants.

Both this study and the linked NIHR-funded feasibility study were registered with the ISRCTN registry (16760995 and 90480705 respectively).

6 Research question 1 - case control study (results)

The previous chapter outlined the methodology to be used for the case control study conducted as part of this thesis. This chapter presents the results of this study, initially describing the results of the recruitment process and the sources of participant recruitment as well as the demographic characteristics of both case and control participants. It then presents the results of the measures evaluated, which included self-report questionnaires and physical testing. A brief summary of the findings, along with a discussion of the limitations, completes the chapter.

6.1 Participants

6.1.1 Cases

As described in Chapter 4, cases for this doctoral project were recruited as part of a NIHR-funded feasibility study [1]. In total, 58 adolescents with AIS were recruited from four specialist NHS sites (Table 6.1).

Table 6.1 Cases recruited by site

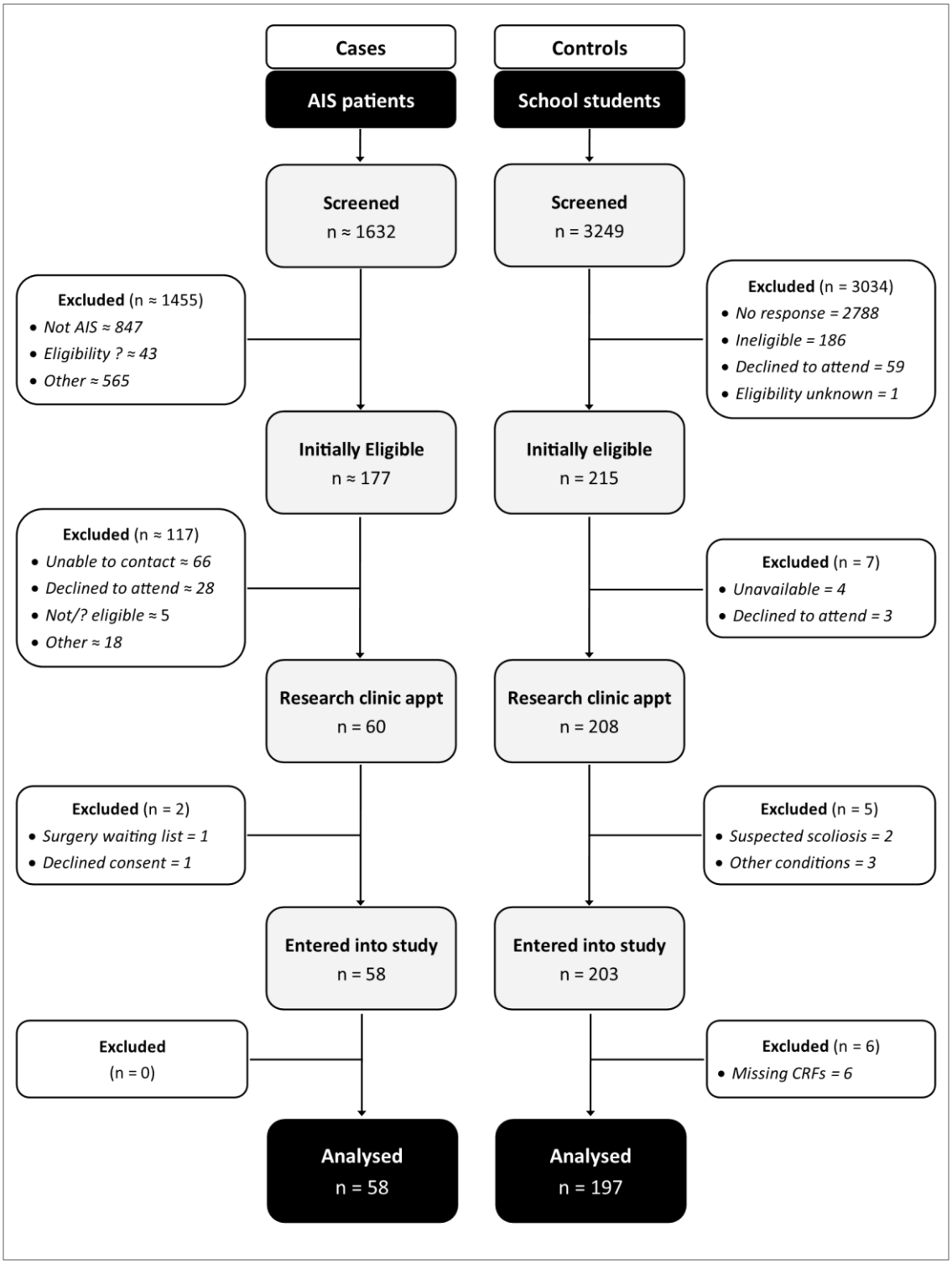
site	n	%
Royal Orthopaedic Hospital, Birmingham	20	34.5
Nuffield Orthopaedic Centre, Oxford	20	34.5
Frenchay Hospital, Bristol	11	19.0
James Cook University Hospital, Middlesbrough	7	12.0
total	58	100

Figure 6.1 gives a CONSORT-style breakdown of case recruitment from initial screening until entry into the study. Recruitment involved three stages with an initial screening in clinic or by patient notes, follow-up by telephone, and subsequent booking of a research clinic appointment where formal consent and measures were taken. Note that figures for early stages are compromised by missing screening data from some sites [1].

From the approximately 1632 patients that were initially screened, around 89% (~1455/1632) were considered ineligible, primarily due to not having AIS. The remaining 177 patients (11%)

appeared to satisfy the requirements of the inclusion/exclusion criteria and attempts were made to contact them regarding potential involvement in the study.

Figure 6.1 Consort diagram case control study*



*some figures approximate due to missing case screening data

Sixty-six of potentially eligible patients (37%) were unable to be contacted. Of the 111 (67%) that could be contacted, 5 (5%) patients were deemed ineligible and a further 28 (25%) declined to be involved, the main reasons cited being lack of time (n≈5) or unwillingness to travel (n≈6). Willingness to be involved was uncertain in a further 18 patients.

Sixty patients were booked in for a research clinic appointment. Of these, 1 was subsequently excluded as they had recently been placed on a waiting list for surgery. Another patient withdrew their consent at the same stage, leaving 58 cases to be enrolled in to the study and whose data went on to be analysed.

6.1.2 Controls

All primary and secondary schools in Coventry, along with all secondary schools in Warwickshire and Oxfordshire, were contacted to request their participation. These schools were identified from lists provided online by relevant local government bodies [2-4]. One school in Leicestershire also expressed an interest in taking part. Of schools contacted, 5% (10/193) gave permission to recruit students (Table 6.2).

Table 6.2 Number of schools involved in control participant recruitment, n (number contacted)

School type	Coventry	Warwickshire	Oxfordshire	Leicestershire	Total
primary	1 (86)	-	-	-	1 (86)
secondary	3 (21)	1 (35)	4 (50)	1 (1)	9 (107)
total	4 (107)	1 (35)	4 (50)	1 (1)	10 (193)

From these 10 schools, approximately 3249 students were approached to recruit age- and sex-matched control participants. Of the initial 215 (7%) students who responded and were both willing and eligible to take part, 3 subsequently withdrew prior to the research clinic appointment and 4 were absent from school due to illness on the day of their appointment (Figure 6.1).

At the research clinic itself, 2 students had findings from clinical observation that suggested possible scoliosis, while a further 3 had conditions that precluded their involvement (2 learning

difficulties/autism; 1 fractured ankle). This left a total of 203 students enrolled into the study. Unfortunately, 6 of these participants failed to complete their questionnaires and self-report measures. Therefore, it was decided to exclude them, leaving a total of 197 for analysis (Table 6.3).

Table 6.3 Control recruitment by site

region	site	n	%
Oxfordshire	Tudor Hall School	65	33.0
	Marlborough C of E School	39	19.8
	King Alfred's Academy	23	11.7
	Kingham Hill School	6	3.0
Leicestershire	Lutterworth High School	19	9.6
Warwickshire	Rugby School	12	6.1
Coventry	Pattison College	20	10.2
	St Gregory's Primary School	7	3.6
	Westwood Academy	4	2.0
	Lyng Hall School	2	1.0
	total	197	100

6.1.3 Matching

Eighty-eight percent of cases (51/58) were matched (by age- and sex) to controls at the desired 1:3-4 ratio (Figure 6.2). The remaining 7 cases (12%), consisting primarily of those in the 16 to 17 yrs age group, were matched to 1 or 2 controls each (Figure 6.3).

The geographical spread of cases and controls relative to the recruiting sites (hospitals and schools respectively) is illustrated in Figure 6.4.

Figure 6.2 Controls per case (by ID)

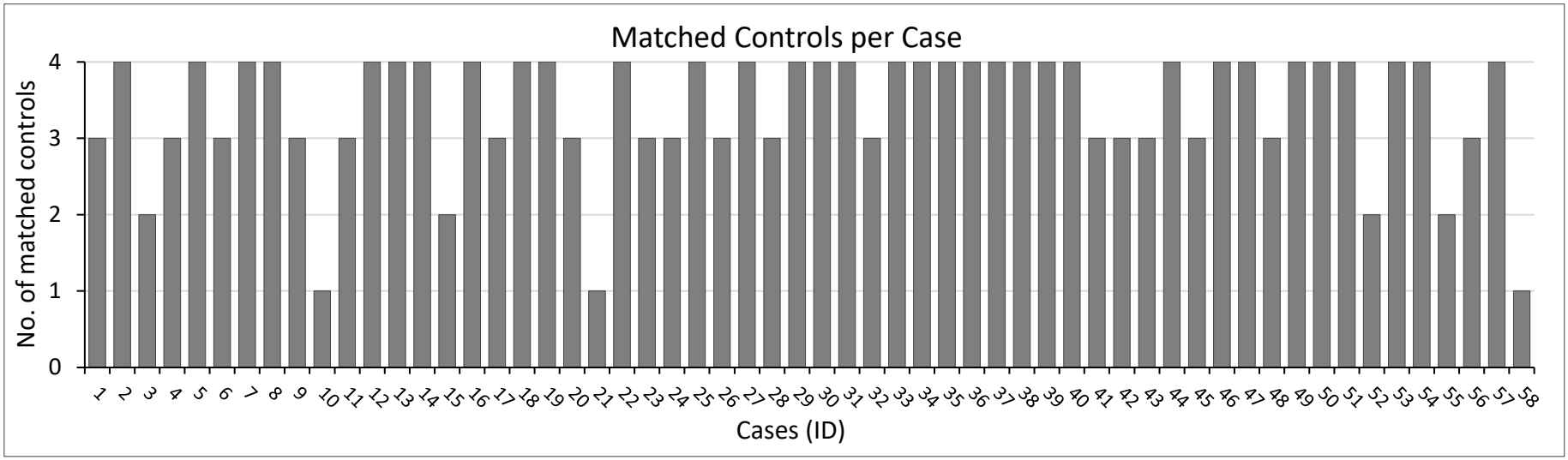


Figure 6.3 Controls per case (by age)

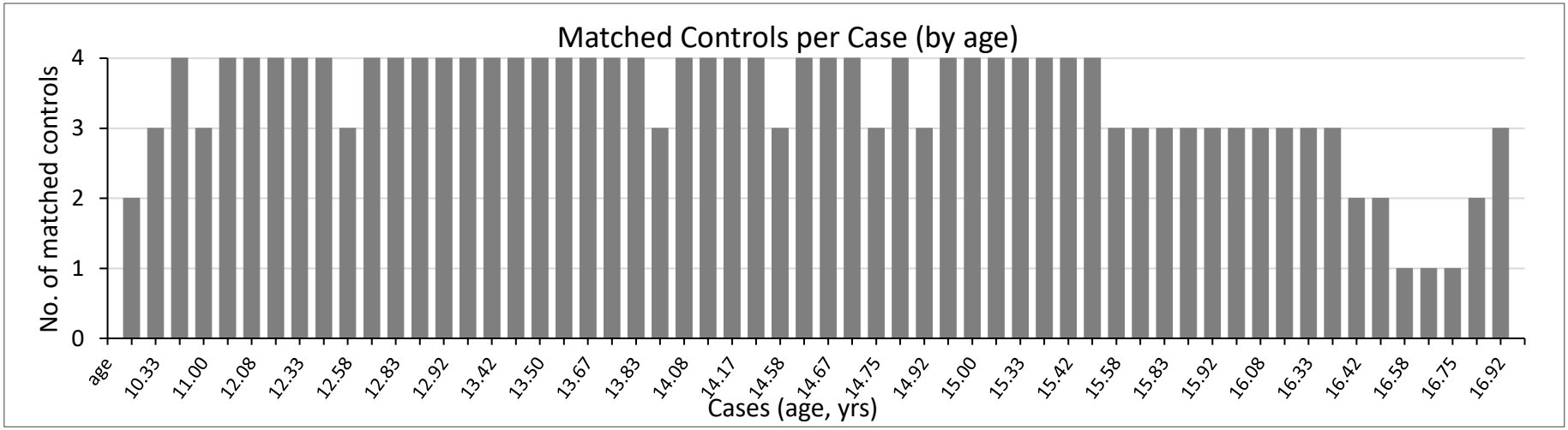
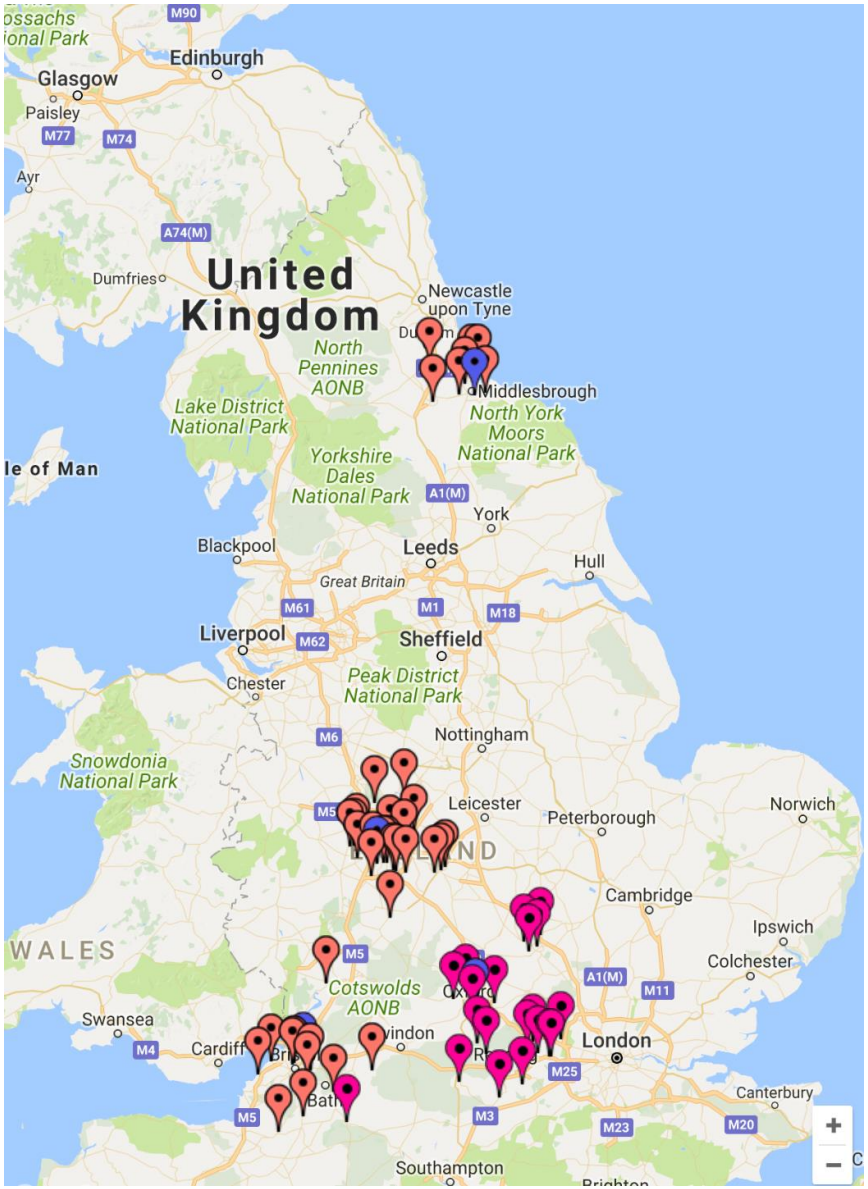
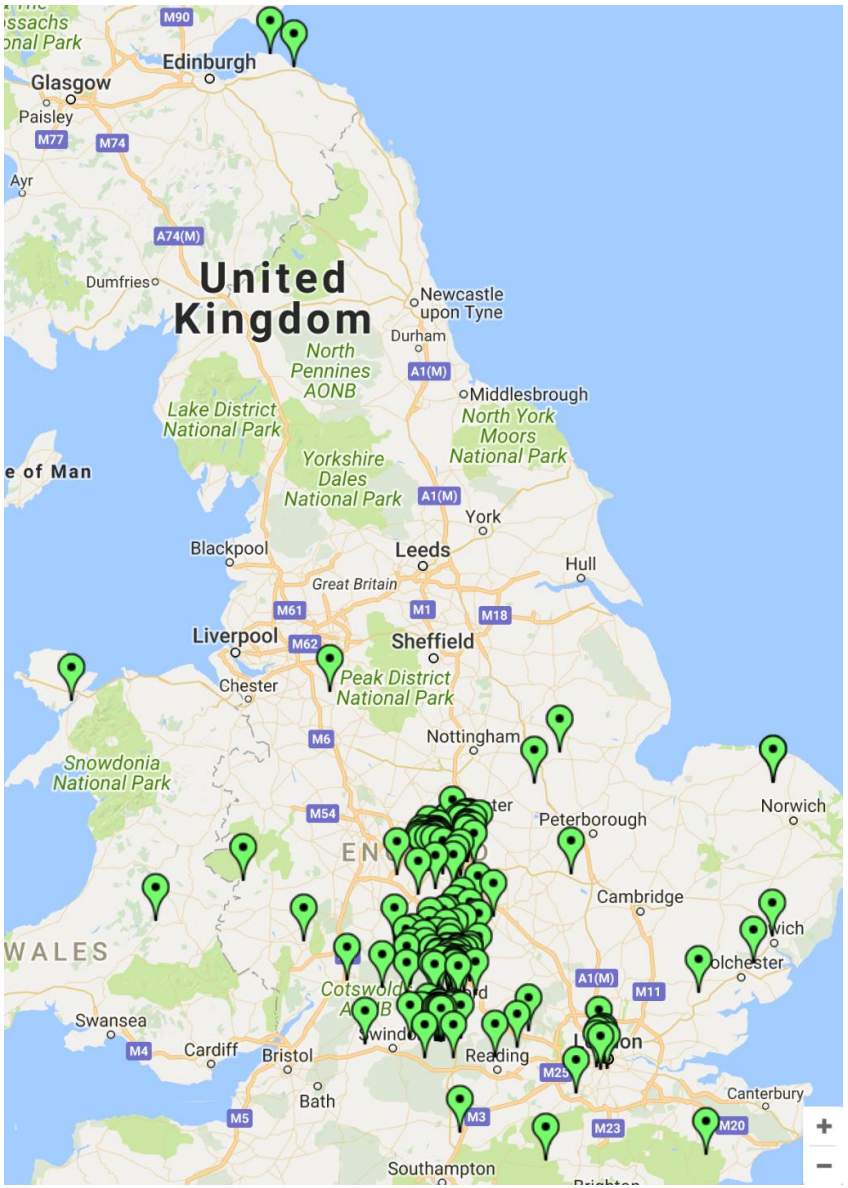


Figure 6.4 a) Case and hospital locations



b) Control and school locations



6.2 Demographics

6.2.1 Matching variables

Sex and age distribution for the two groups are described in Table 6.4 and Table 6.5. The ratio of female to male was equal between groups (≈5:1). Average age and age distribution was also very similar with a difference in mean age between groups equivalent to 2.4 months.

Although participants across the range from 10 to 17 yrs were recruited in both groups, the age distribution displayed a slight skew towards older age groups (Figure 6.5).

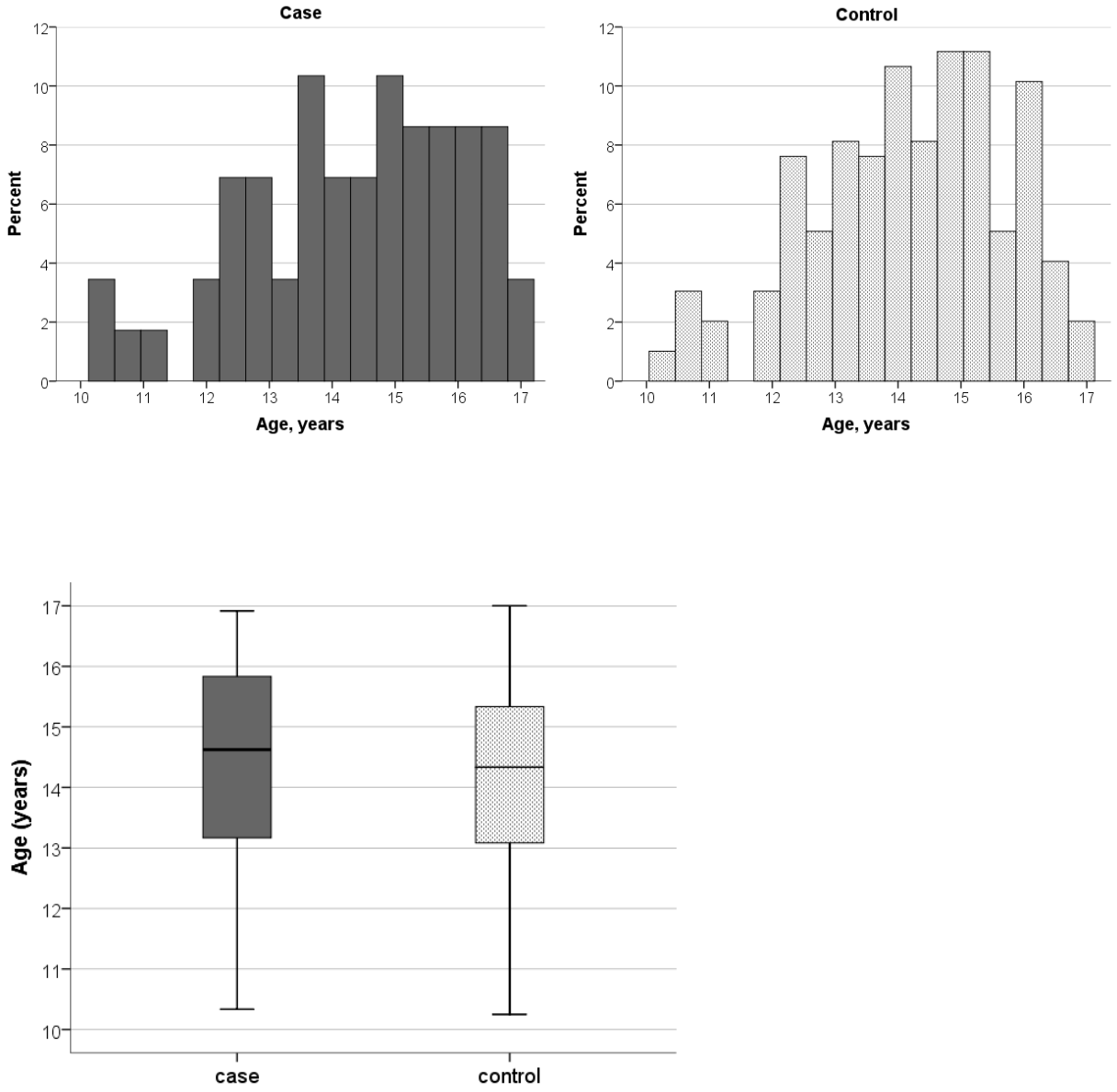
Table 6.4 Sex

	case		control		total	
	n	%	n	%	n	%
female	48	82.8	162	82.2	210	82.4
male	10	17.2	35	17.8	45	17.6
total	58	100	197	100	255	100

Table 6.5 Age (years)

	n	mean	sd	SE	95% CI	median	IQR	min	max
case	58	14.4	1.72	0.23	13.9, 14.8	14.6	13.1, 15.9	10.3	16.9
control	197	14.2	1.54	0.11	13.9, 14.4	14.3	13.1, 15.3	10.3	17.0

Figure 6.5 Histogram & boxplot of age by group



6.2.2 Other demographic variables

Self-reported ethnicity, handedness, family history of scoliosis and whether subjects had reached puberty are reported in Table 6.6. Self-reported age of puberty onset, gross weekly income, and measures of height, weight and BMI are described in Table 6.7. The 'age of puberty onset' includes only those who reported having reached puberty.

A greater proportion of case participants stated they had reached puberty at the time of inclusion into the study (81% v 71%). A greater proportion of case participants also reported other family members with scoliosis (39% v 8%).

Table 6.6 Other demographic variables 1

	case		control		total	
	n	%	n	%	n	%
Ethnicity						
White	52	91.2	176	89.8	228	90.1
Indian	0	0.0	3	1.5	3	1.2
Chinese	1	1.8	1	0.5	2	0.8
Mixed	0	0	11	5.6	11	4.3
Black/Black British	3	5.3	3	1.5	6	2.4
Other	1	1.8	2	1.0	3	1.2
subtotal	57	100	196	100	253	100
missing	1	1.7	1	0.5	2	0.8
Handedness (EHI)						
Right	50	87.7	164	83.2	214	84.3
Left	1	1.8	9	4.6	10	3.9
Mixed	6	10.5	24	12.2	30	11.8
subtotal	57	100	197	100	254	100
missing	1	1.7	0	0	1	0.4
Puberty status						
yes	46	80.7	140	71.1	186	73.2
no	11	19.3	57	28.9	68	26.8
subtotal	57	100	197	100	254	100
missing	1	1.7	0	0	1	0.4
Family history of scoliosis						
yes	17	38.6	15	7.6	32	13.3
no	27	61.4	182	92.4	209	86.7
subtotal	44	100	197	100	241	100
missing	14	24.1	0	0	14	5.5

Table 6.7 Other demographic variables 2

	n	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
Age puberty onset (yrs)*										
case	45	12.49	1.06	0.16	12.17, 12.81	13.00	12-13	9.00	15.00	1 (2.2)
control	137	12.35	1.04	0.09	12.17, 12.53	12.00	12-13	9.00	15.00	3 (2.1)
Income, postcode (weekly gross £)										
case	58	748.79	231.97	30.46	687.8, 809.8	700.00	587.5, 860	430.00	1510.00	0 (0)
control	183	833.33	188.83	13.96	805.8, 860.9	860.00	690, 920	440.00	1710.00	14 (7.7)
Standing height, cm										
case	58	162.66	11.00	1.44	159.8, 165.6	164.50	156, 170.3	127.00	187.00	0 (0)
control	197	162.44	9.48	0.68	161.1, 163.8	163.00	157.8, 168	122.50	186.00	0 (0)
Weight, kg										
case	58	52.74	11.86	1.56	49.62, 55.86	54.00	44.5, 61	28.00	75.00	0 (0)
control	197	53.94	11.06	0.79	52.39, 55.5	54.40	46.2, 59.7	28.90	89.20	0 (0)
Body mass index (BMI)										
case	58	19.55	3.19	0.42	18.71, 20.39	19.57	17.2, 21.2	13.45	27.48	0 (0)
control	197	20.32	3.25	0.23	19.86, 20.78	20.00	18, 22.1	14.36	35.25	0 (0)

* of those who reported reaching puberty in table 5.6

6.2.3 Spinal deformity characteristics - cases

There was almost an equal split between single (52.6%, 30/58) and double (45.6%, 26/58) curve types, with one triple curve. Most of the primary curves (defined by the largest Cobb angle) were reported as located in the thoracic region and convex to the right (Table 6.8).

Most participants (82%, 46/58) reported that they did not use a brace.

Table 6.8 Brace use & spinal deformity characteristics of 58 case participants

	Category	case		missing
		n	%	n (%)
Brace	Yes	10	17.9	2 (3.4)
	No	46	82.1	
Curve type	Single	30	52.6	1 (1.7)
	Double	26	45.6	
	Triple	1	1.8	
Curve direction*	Right	37	64.9	2 (1.7)
	Left	20	35.1	
Curve location*	thoracic	36	62.1	0 (0)
	thoracolumbar	4	6.9	
	lumbar	17	29.3	
	unknown	1	1.7	
Risser sign	0 - 0%	7	19.4	22 (37.9)
	1 - 25%	3	8.3	
	2 - 50%	2	5.6	
	3 - 75%	7	19.4	
	4 - 100%	11	30.6	
	5 - skeletal maturity	6	16.7	

* of primary curve

The Risser sign was not recorded in over a third of all cases. The main reason for the lack of recording of the Risser sign was due to the images not being sufficiently extensive to allow for its calculation.

In those where it was recorded, nearly half (47.2%, 17/36) were classified as in the final stages or having already reached skeletal maturity. The rest were split almost equally between the

very early stages of skeletal maturation (27.8%, 10/36), with a Risser sign of 0 to 1, or mid-stage (25%, 9/36), with a Risser sign of 2 to 3. The main reason for the lack of recording of the Risser sign was due to the images not being sufficiently extensive to allow for its calculation.

The Cobb angle of the main curve ranged from 14 to 50° (mean = 34.02°, SD 10.0) indicating that the cohort of cases ranged from mild to severe spinal deformity (Table 6.9 and Figure 6.6). Absolute values for coronal and sagittal balance are also presented (Table 6.9 and Figure 6.7 and Figure 6.8). On average, sagittal and coronal imbalances were small and do not represent a clinically significant departure from normal [5].

Table 6.9 Cobb angle (main curve) and spinal balance (absolute values) - descriptive statistics

Variable	n	mean	sd	SE	95% CI		median	min	max	IQR	missing n (%)
Cobb angle (°)	57	34.0	10.0	1.32	31.4	36.7	34.0	14.0	50.0	27-41	1 (1.7)
Coronal balance (mm)	55	17.8	13.6	1.83	14.1	21.4	15.0	0	50.0	8-27	3 (5.2)
Sagittal balance (mm)	42	37.8	28.8	4.44	28.8	46.7	29.0	0	97.0	16.8-54	16 (27.6)

Figure 6.6 Cobb angle primary curve - histogram & boxplot

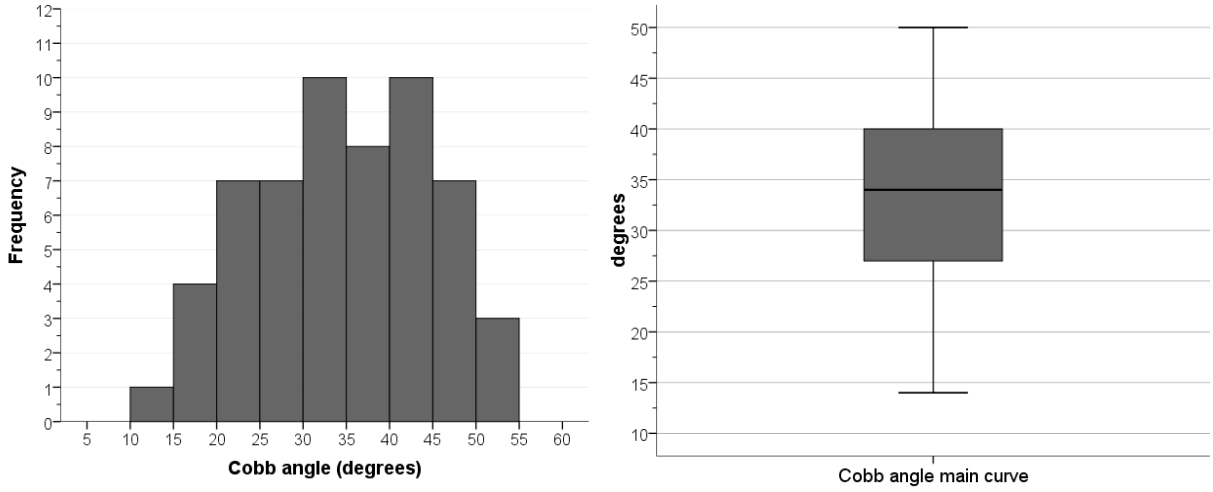


Figure 6.7 Coronal balance - histogram & boxplot

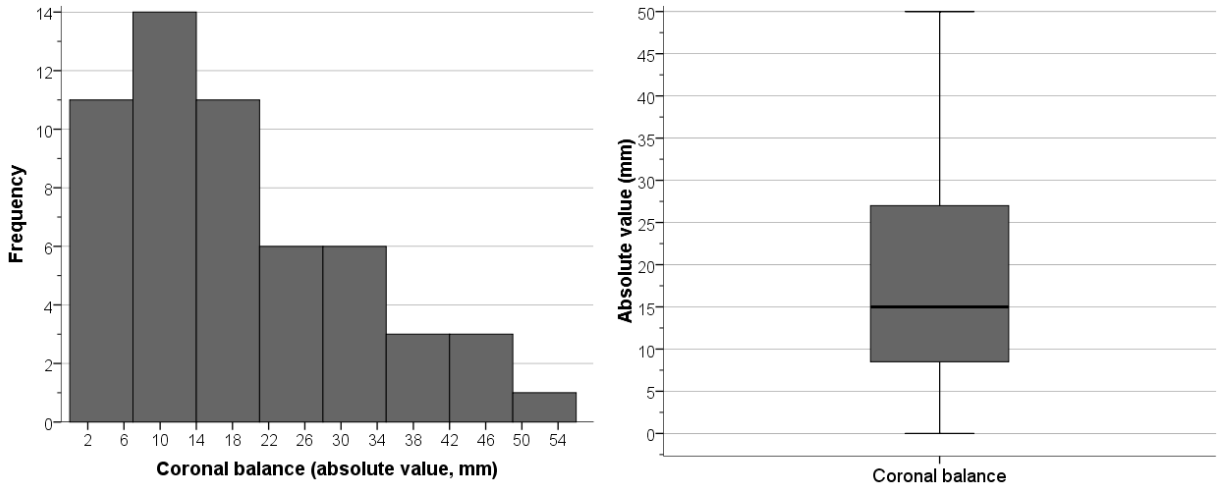
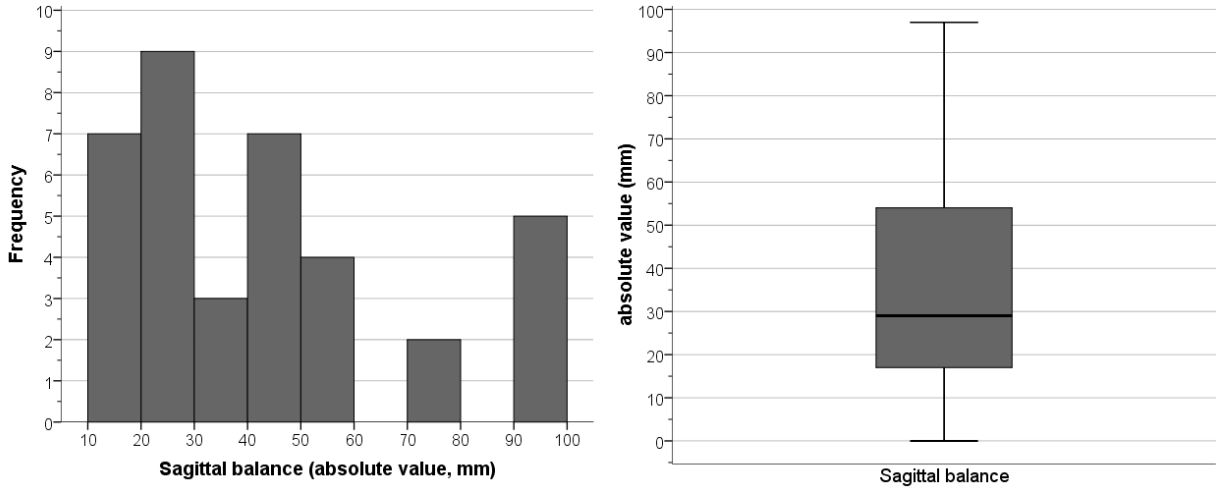


Figure 6.8 Sagittal balance - histogram & boxplot



6.3 Spinal Appearance Questionnaire (SAQ)

6.3.1 Appearance scale

Control participants scored towards the lower (i.e. better) end of the scale indicating that they tended to select the images that represented a more 'normal' posture or alignment (Figure 6.9). In contrast, cases scores were more evenly distributed. This is reflected in the differences in the mean and median scores between the two groups with cases recording double the average scores than controls (Table 6.10). Statistical analysis (Mann-Whitney U test) revealed that the 11 point difference in medians between the cases and controls was statistically significant (median values = 22 and 11 respectively; U=266.00, z=11.07, p<0.001, r=0.70).

A point-biserial correlation was run to determine the relationship between perceived spinal appearance and group type (i.e. case or control). Group type was significantly related to the SAQ appearance score (r_{pb} = 0.812; 95% BCa CI 0.741, 0.870; p<0.001) and shared 65.9% of the variability in SAQ appearance score (r_{pb}^2=0.659) (Table 6.11).

6.3.2 Expectations scale

Control participant responses to the questions regarding desire/expectation for improvement in posture and alignment were much lower than cases (Table 6.10 and Figure 6.10). This reflected less of a desire amongst controls to change their alignment. The 9 point difference in median scores between cases and controls was statistically significant (Mann-Whitney U test, median values = 13 and 4 respectively; U=865.5, z=10.10, p<0.001, r=0.64).

A point-biserial correlation was run to determine the relationship between expectations and group type (i.e. case or control). Group type was significantly related to the SAQ expectations score (r_{pb} = 0.732; 95% BCa CI 0.644, 0.805; p<0.001) and shared 53.6% of the variability in SAQ expectations score (r_{pb}^2=0.536) (Table 6.11).

6.3.3 Total score

As would be expected, the combined score followed a similar pattern to the individual scales with controls scoring better (i.e. lower) than cases (Table 6.10 and Figure 6.11). Statistical analysis revealed that the 20 point difference in medians between cases and controls was

statistically significant (median values = 36 and 16 respectively; U=331.5, z=10.72, p<0.001, r=0.68).

A point-biserial correlation was run to determine the relationship between SAQ total score and group type (i.e. case or control). Group type was significantly related to the total score (r_{pb} = 0.818; 95% BCa CI 0.759, 0.870; p<0.001) and shared 66.9% of the variability in SAQ total score (r_{pb}^2=0.669) (Table 6.11).

Table 6.10 SAQ descriptive statistics

	n	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
SAQ appearance (10 best - 50 worst)										
case	56	22.6	5.91	0.79	21.0, 24.2	22.0	18-27.8	11	38	2 (3.4)
control	196	11.5	2.12	0.15	11.2, 11.8	11.0	10-12	10	27	1 (0.5)
SAQ expectations (4 best - 20 worst)										
case	56	13.1	4.74	0.63	11.9, 14.4	13.0	9.25-17	4	20	1 (1.7)
control	196	5.31	2.36	0.17	4.97, 5.64	4.0	4-5	4	16	2 (1.0)
SAQ total score (14 best - 70 worst)										
case	55	35.6	9.33	1.26	33.0, 38.1	36.0	28-43	15	55	3 (5.2)
control	195	16.8	3.76	0.27	16.3, 17.3	16.0	14-18	14	38	2 (1.0)

Figure 6.9 SAQ appearance histogram and box plot

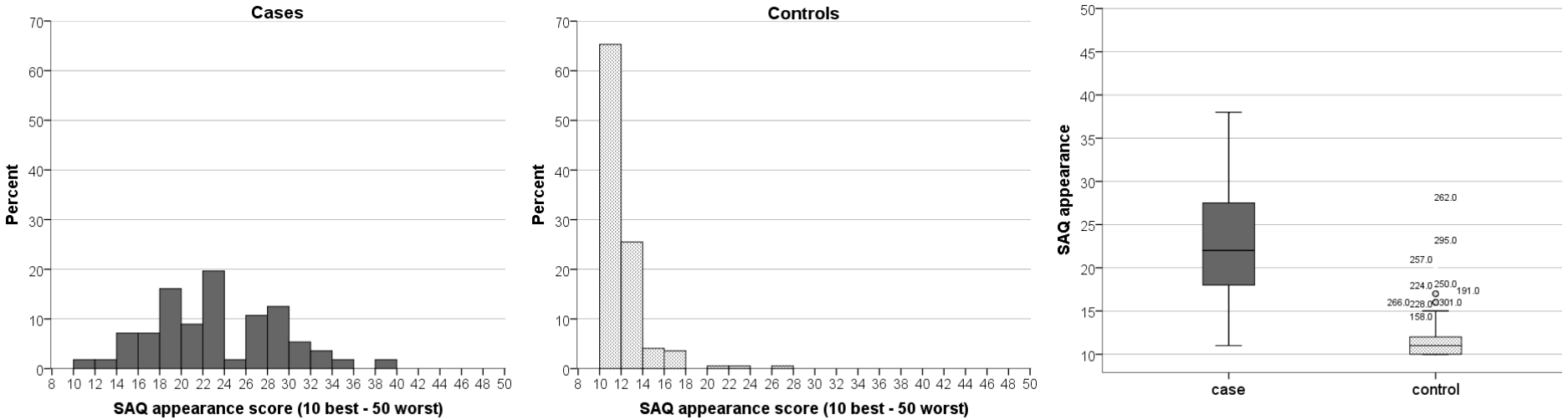


Figure 6.10 SAQ expectations histogram and boxplot

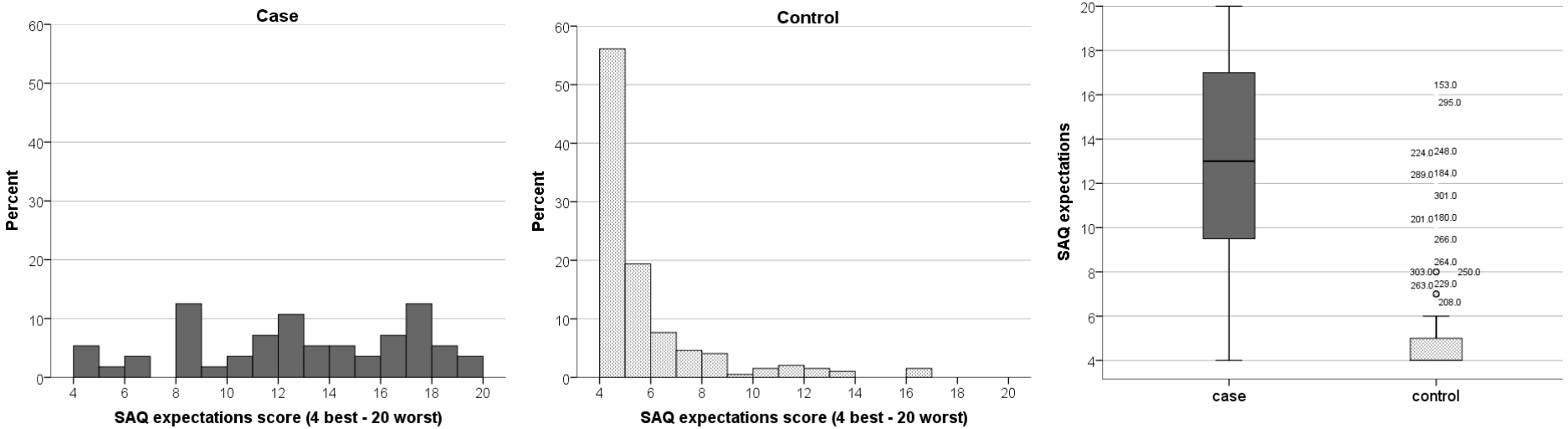


Figure 6.11 SAQ total score histogram & boxplot

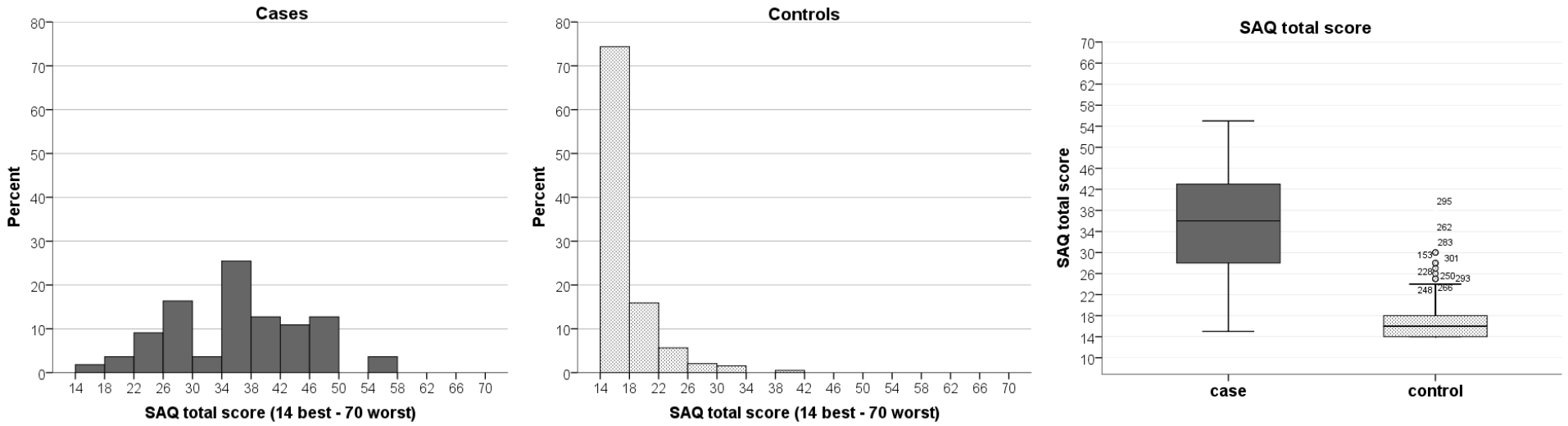


Table 6.11 SAQ - results of statistical analyses

measure	scale	Difference between means/medians							Correlation Group type v SAQ		
		test	group	diff medians	U	z	p-value	effect size**	r_{pb}	95% BCa CI	r_{pb}^2
SAQ	appearance	Mann-Whitney U	case v control	11	266.0	11.07	<0.001*	0.70	0.812*	0.741, 0.870	0.659
	expectations	Mann-Whitney U	case v control	9	865.5	10.10	<0.001*	0.64	0.732*	0.644, 0.805	0.536
	total	Mann-Whitney U	case v control	20	331.5	10.72	<0.001*	0.68	0.818*	0.759, 0.870	0.669

* statistically significant; ** Pearson's r

6.4 Kinaesthetic & Proprioceptive Awareness Questionnaire (KPAQ)

Both case and control scores for the KPAQ were clustered in the upper half of the scoring range indicating higher kinaesthetic and proprioceptive awareness (Figure 6.12). Controls reported slightly higher scores with a 2.5 point difference in medians between groups (Table 6.12). This was statistically significant (Mann-Whitney U test; median values = 48 and 50.5 respectively; U=4262.00, z=-2.263, p=0.023, r=-0.14).

A point-biserial correlation was run to determine the relationship between kinaesthetic and proprioceptive awareness and group type. Group type was not significantly related to the KPAQ score (r_{pb} = 0.114; 95% BCa CI -0.001, 0.273; p=0.074) and shared only 1.3% of the variability in KPAQ total score (r_{pb}^2=0.013) (Table 6.13).

Table 6.12 KPAQ descriptive statistics (12 worst - 60 best)

	n	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
case	56	47.30	6.23	0.83	45.6, 48.9	48.0	41.3-52	36	60	2 (3.4)
control	190	49.43	8.40	0.61	48.2, 50.6	50.5	43-57	26	60	7 (3.6)

Figure 6.12 KPAQ histograms & boxplot

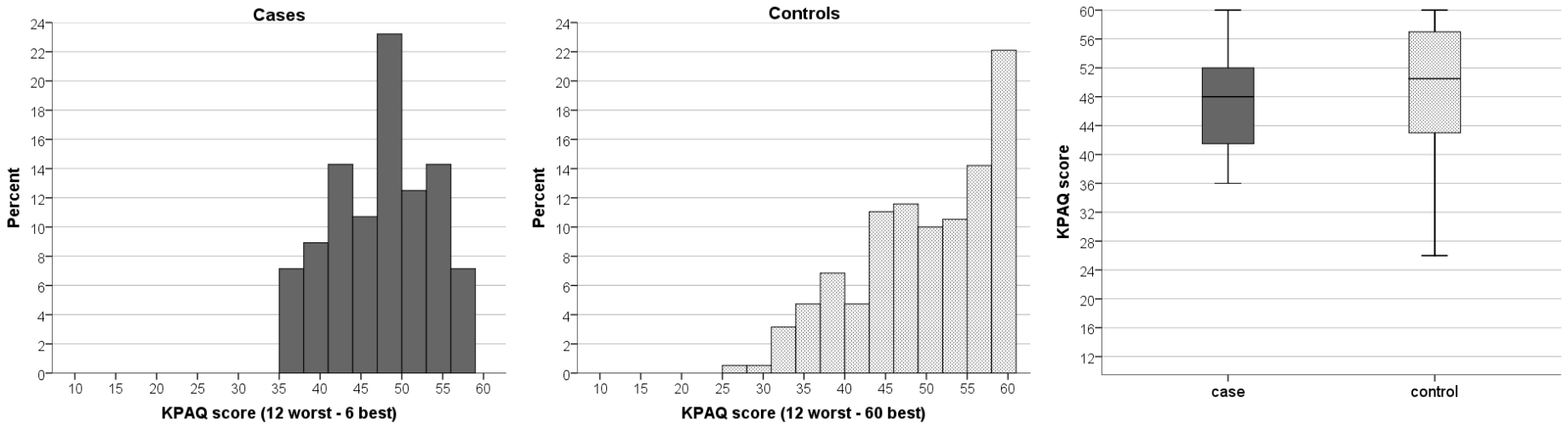


Table 6.13 KPAQ - results of statistical analyses

measure	scale	Difference between means/medians							Correlation Group type v KPAQ		
		test	group	diff medians	U	z	p-value	effect size**	r_{pb}	95% BCa CI	r_{pb}^2
KPAQ	total	Mann-Whitney U	case v control	-2.5	4262.0	-2.263	0.023*	-0.14	0.114	-0.001, 0.237	0.013

* statistically significant; ** Pearson's r

6.5 Scoliosis Research Society questionnaire (SRS-22r)

6.5.1 Function scale

Both groups were negatively skewed with the majority of participants scoring at the upper end of the scale indicating higher function (Figure 6.13). Despite no difference in median scores (Table 6.14), statistical analysis revealed a significant difference between groups in favour of the control group (Mann-Whitney U test; median values = 4.8; U=4480.00, z=-2.47, p=0.013, r=-0.15). This is because the Mann-Whitney U test compares distribution or rankings between groups rather than testing the difference in medians directly [6].

A point-biserial correlation was run to determine the relationship between function and group type. Group type was significantly related to the function score (r_{pb} = 0.240; 95% BCa CI 0.087, 0.389; p<0.001) although it shared only 5.8% of the variability in SRS-22r function score (r_{pb}^2=0.058) (Table 6.15).

6.5.2 Pain scale

Controls generally experienced little if any pain as evidenced by the clustering of scores towards the upper end of the scale (Table 6.14). In contrast, case scores were more evenly spread suggesting they experienced more problems with pain (Figure 6.14). The 0.6 point difference in median scores between groups was statistically significant (Mann-Whitney U test; median values = 4.2 and 4.8 respectively; U=2126.00, z=-7.341, p<0.001, r=-0.46).

A point-biserial correlation was run to determine the relationship between pain and group type. Group type was significantly related to the pain score (r_{pb} =0.535; 95% BCa CI 0.436, 0.629; p<0.001) and shared 28.6% of the variability in SRS-22r pain score (r_{pb}^2=0.286) (Table 6.15).

6.5.3 Self-image scale

Results for the self-image scale were similar to the pain scale with cases reporting lower scores and therefore greater problems with self-image (Figure 6.15 and Table 6.14). The 0.97 point difference in means (-0.76 to -1.78 95% CI) between cases and controls was statistically significant (mean values = 3.40 and 4.37 respectively; independent t-test, t=9.39, df=70.7, p<0.001, d = -0.50).

A point-biserial correlation was run to determine the relationship between self-image and group type. Group type was significantly related to the self-image score (r_{pb} =0.594; 95% BCa CI 0.509, 0.680; p<0.001) and shared 35.3% of the variability in SRS-22r self-image score (r_{pb}^2=0.353) (Table 6.15).

6.5.4 Mental health scale

The average and distribution of scores was very similar between groups (Table 6.14 and Figure 6.16). The 0.2 difference in medians between cases and controls was not statistically significant (median values = 4.2 and 4.0 respectively; Mann-Whitney U test, U=5519.50, z=0.196, p=0.846, r=0.01).

A point-biserial correlation was run to determine the relationship between mental health and group type. Group type was not significantly related to the mental health score (r_{pb} =0.067; 95% BCa CI -0.096, 0.226; p=0.284) and shared only 0.4% of the variability in SRS-22r mental health score (r_{pb}^2=0.004) (Table 6.15).

6.5.5 Subtotal score

The differences between groups for the combined SRS-22r score were driven primarily by the differences in the pain and self-image subscales (Figure 6.17 and

Table 6.14). This resulted in cases reporting lower and therefore worse subtotal scores on average with a difference in means of 0.5 (-0.34 to -0.66 95% CI) which was statistically significant (independent t-test, t=6.27, df=65.68, p<0.001, d = -0.62).

A point-biserial correlation was run to determine the relationship between the total score and group type. Group type was significantly related to the total score (r_{pb} =0.476; 95% BCa CI 0.361, 0.586; p<0.001) and shared 22.7% of the variability in SRS-22r total score (r_{pb}^2=0.227) (Table 6.15).

Table 6.14 SRS-22r scores

scale (1 worst - 5 best)	group	n	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
function	case	57	4.60	0.45	0.06	4.48, 4.72	4.80	4.2, 5.0	3.40	5.00	1 (1.7)
	control	197	4.79	0.27	0.02	4.75, 4.83	4.80	4.6, 5.0	3.80	5.00	0
pain	case	57	3.96	0.76	0.1	3.76, 4.17	4.20	3.4, 4.6	1.80	5.00	1 (1.7)
	control	197	4.7	0.37	0.03	4.64, 4.75	4.80	4.5, 5.0	3.20	5.00	0
self image	case	57	3.40	0.74	0.1	3.20, 3.60	3.40	2.8, 3.8	1.80	5.00	1 (1.7)
	control	197	4.37	0.49	0.03	4.30, 4.44	4.40	4.0, 4.8	3.00	5.00	0
mental health	case	57	3.9	0.9	0.12	3.66, 4.14	4.2	3.3, 4.6	1.8	5	1 (1.7)
	control	197	4.01	0.59	0.04	3.93, 4.09	4.0	3.6, 4.4	1.8	5	0
total score	case	57	3.97	0.58	0.08	3.81, 4.12	4.10	3.5, 4.4	2.70	4.85	1 (1.7)
	control	197	4.47	0.31	0.02	4.42, 4.51	4.50	4.3-4.7	3.55	5.00	0

Figure 6.13 SRS-22r function histogram & boxplot

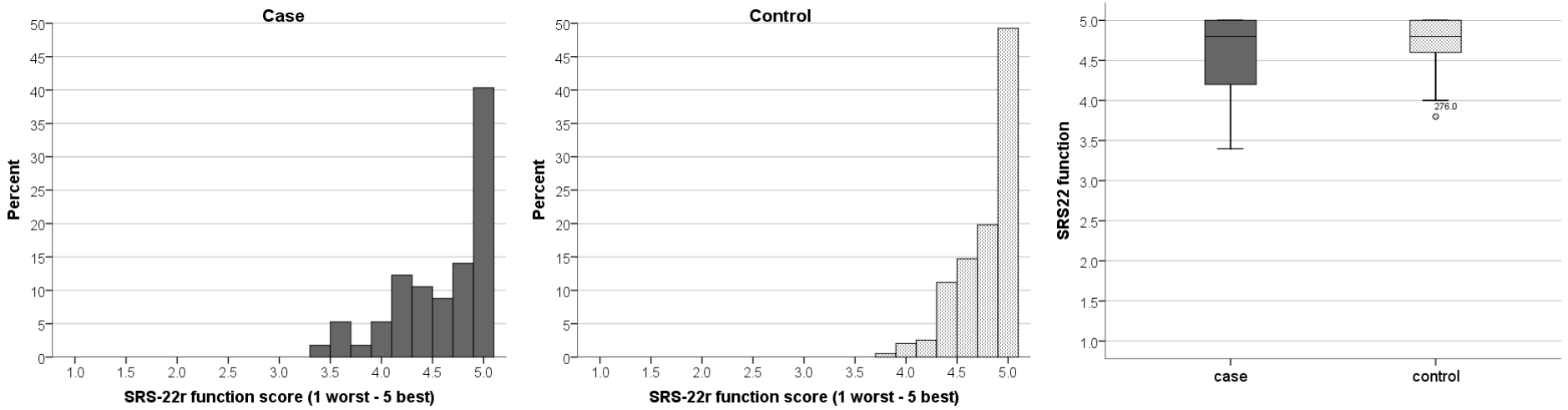


Figure 6.14 SRS-22r pain histogram & boxplot

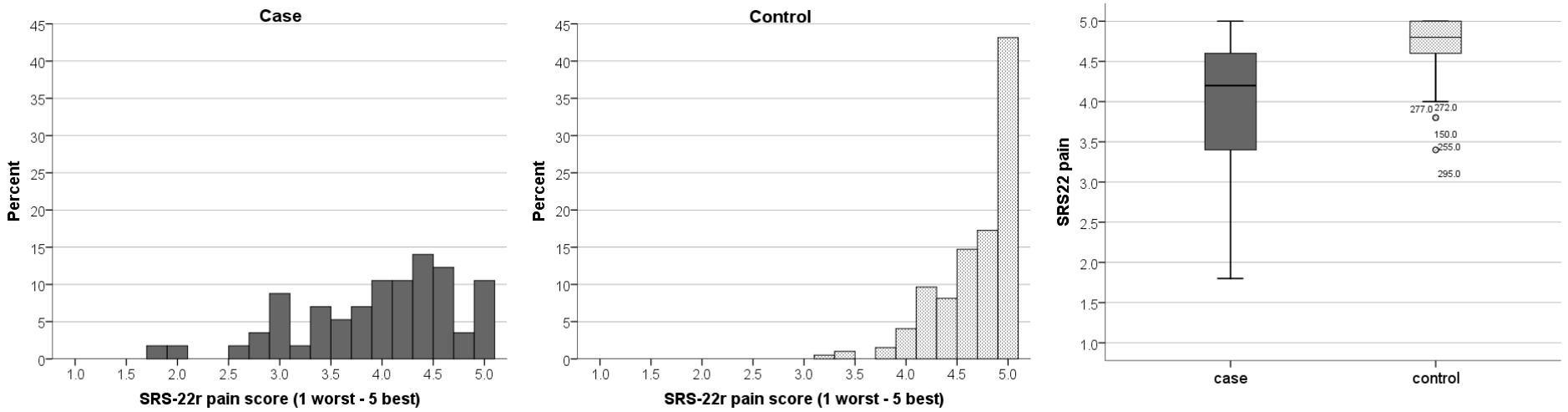
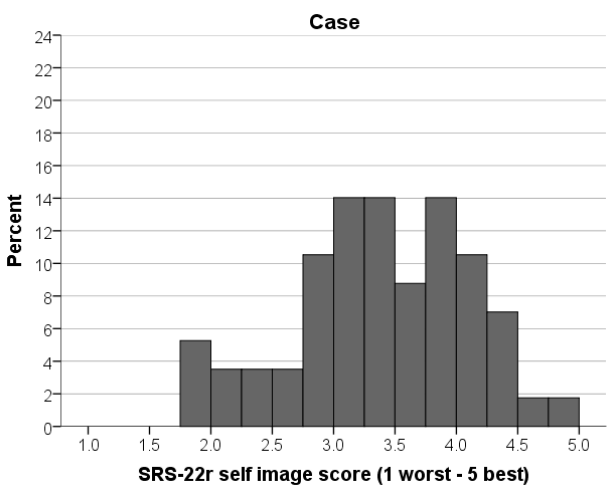
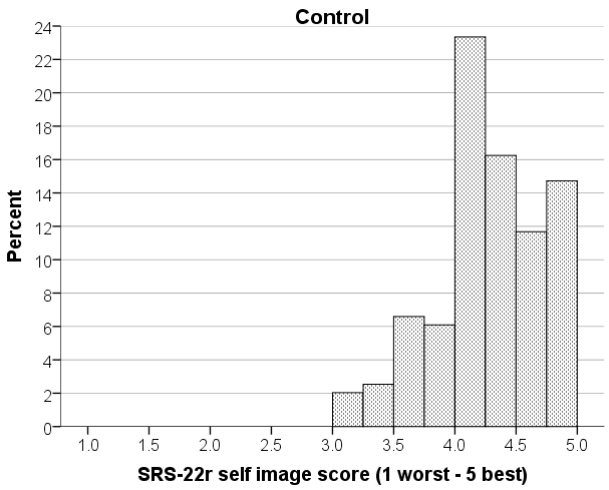


Figure 6.15 SRS-22r self-image histogram & boxplot





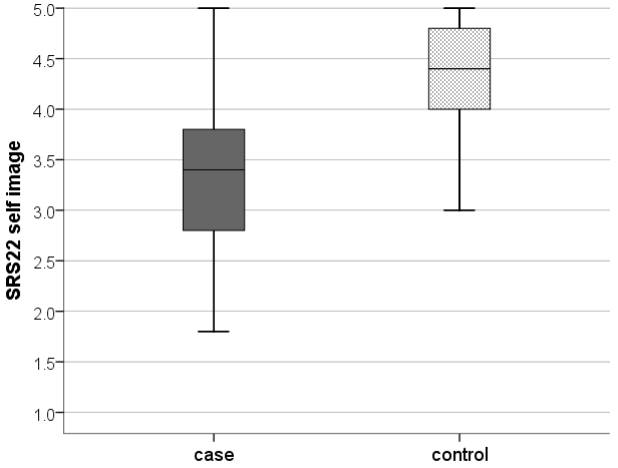
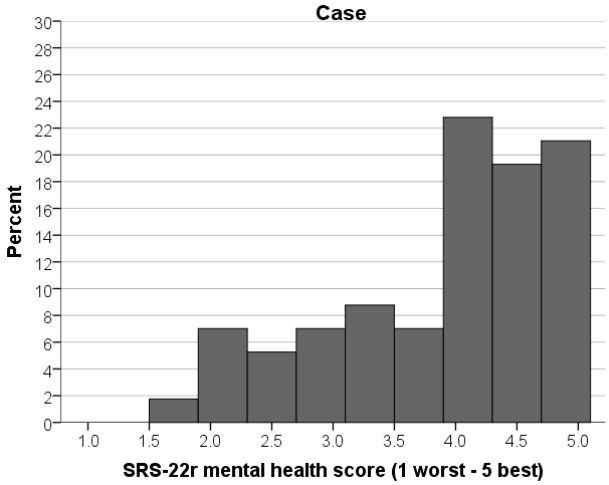
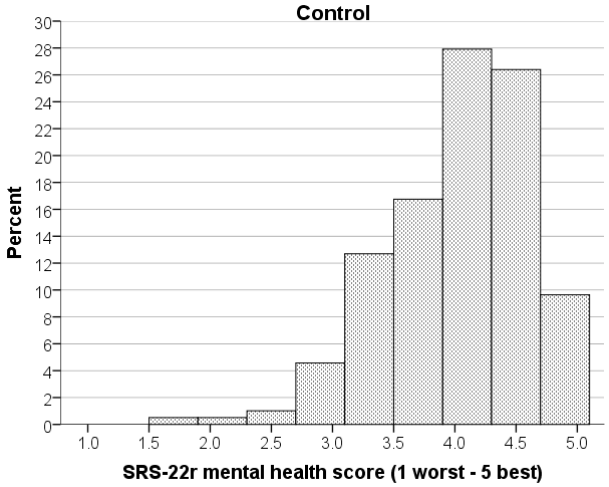


Figure 6.16 SRS-22r mental health histogram & boxplot





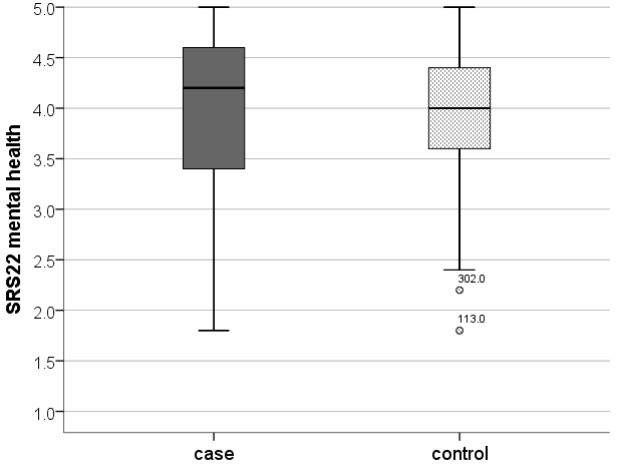


Figure 6.17 SRS-22r total score histogram & boxplot

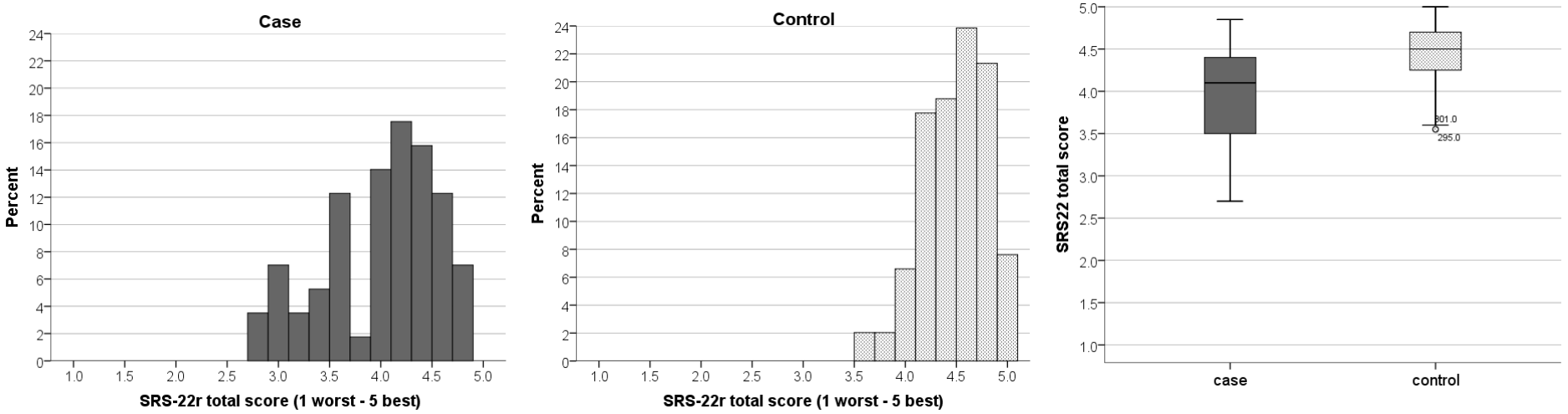


Table 6.15 SRS-22r - results of statistical analyses

scale	Difference between means/medians							Correlation Group type v SRS-22r		
	test	diff medians	U	z	p-value		effect size**	r_{pb}	95% BCa CI	r_{pb}^2
function	Mann-Whitney U	0	4480.0	-2.47	0.013*		-0.15	0.240*	0.087, 0.389	0.058
pain	Mann-Whitney U	-0.6	2126.0	-7.34	<0.001*		-0.46	0.535*	0.436, 0.629	0.286
mental health	Mann-Whitney U	0.20	5519.5	0.20	0.846		0.01	0.067	-0.096, 0.226	0.004
scale	**test**	**diff means**	**95% CI**	**t**	**df**	**p-value**	**effect size¥**	**r_{pb}**	**95% BCa CI**	**r_{pb}^2**
self-image	independent t-test	-0.97	-0.76, -1.78	9.39	70.7	<0.001*	-0.50	0.594*	0.509, 0.680	0.353
total	independent t-test	-0.50	-0.34, -0.66	6.27	65.7	<0.001*	-0.62	0.476*	0.361, 0.586	0.227

* statistically significant; ** Pearson's r; ¥ Cohen's d

6.6 EQ 5D - 3L

Frequency of responses for each domain is reported in

Table 6.16 and graphically in Figure 6.18. In general, more than 70% of both cases and controls reported no problems across all domains apart from pain. Due to the very low number of responses for 'extreme problems' across all domains, this category was combined with 'some problems' for further analysis (Table 6.17).

6.6.1 Mobility

The majority of participants in both groups stated they had no problems walking about. However, there were notable discrepancies between observed and expected frequencies for both groups (Table 6.17). This is reflected in the large differences between the proportion of cases and controls reporting problems as opposed to those reporting none. Cases made up 71.4% (10/14) of all participants who described mobility problems but only 19.7% (47/239) of those with no issues. In contrast, controls formed 28.6% (4/14) of participants with problems but 80.3% (192/239) of those without. Only one (case) participant reported extreme problems with mobility.

Fisher's exact test results indicated that the null hypothesis (group-type and the presence of mobility problems were independent) can be rejected (χ^2=20.30, df=1, p<0.001). This suggests that there is an association between group type and whether or not participants had problems (Table 6.19).

Based on the odds ratio, the odds of participants having problems with mobility were 10.21 times higher for cases than controls (3.1 to 34.0 95% CI, z=3.79, p=0.0002).

6.6.2 Self-care

Virtually all participants in both groups reported no problems with self-care. Only small differences existed between observed and expected counts, as well as between proportions with or without problems within each group (cases with/without problems 33.3% / 22.4%; controls 66.7% / 77.6%) (Table 6.17). One (control) participant reported extreme problems with self-care.

Statistical analysis concluded with a non-significant result (χ^2=0.203, df=1, p=0.537, Fisher's exact test; OR=1.73, 0.15 to 19.5 95% CI, z=0.445, p=0.656), therefore the null hypothesis could not be rejected (Table 6.19). Consequently, there is no evidence of an association between group type and reported problems, i.e. both cases and controls are just as likely to have problems (or not) with self-care.

6.6.3 Usual activities

The results for usual activities were very similar to those reported for mobility. Again there were notable differences between observed and expected frequencies, as well as in the proportion of those reporting problems versus those that didn't within groups (cases with/without problems 66.7% / 19.1%; controls 33.3% / 80.9%) (Table 6.17). One control participant reported they were unable to perform usual activities (i.e. extreme problems).

Fisher's exact test was significant (χ^2=21.77, df=1, p<0.001), leading to rejection of the null hypothesis and suggesting a significant association between group type and whether or not participants reported problems (Table 6.19).

Based on the odds ratio, the odds of participants having problems with usual activities were 8.49 times higher for cases than controls (3.0 to 23.8 95% CI, z=4.06, p<0.001).

6.6.4 Pain or discomfort

The most notable feature of the results for the pain domain is that, while the majority of control participants followed the established pattern of reporting no problems, the majority of cases reported they suffered from at least moderate pain or discomfort (Figure 6.18 and Table 6.17). One control and one case participant reported extreme pain or discomfort.

The lack of equality between observed/expected frequencies and in the proportions of those with/without problems within groups, suggested that the response pattern (pain/no pain) was heavily influenced by group type.

This was confirmed by statistical testing. The null hypothesis was rejected suggesting a statistically significant association between group type (case v control) and whether or not participants reported pain or discomfort (χ^2= 56.301, df=1, p<0.001).

Based on the odds ratio, the odds of participants having pain or discomfort were 10.31 times higher for cases than controls (5.3 to 20.1 95% CI, z=6.84, p<0.001) (Table 6.19).

6.6.5 Anxiety or depression

The majority of participants reported no problems although a sizeable minority indicated that they suffered from at least a moderate level of anxiety or depression (≈20%). However, the observed/expected frequencies and proportions of those who described suffering some anxiety compared to those that reported none within groups were roughly equal (cases with/without anxiety 31.3% / 20.5%; controls 68.8% / 79.5%) (Table 6.17). Three cases and one control reported feeling extremely anxious or depressed.

Statistical testing was non-significant therefore the null hypothesis could not be rejected (χ^2= 2.581, df=1, p=0.125; OR=1.76, 0.88 to 3.55 95% CI, z=1.593, p=0.111) (Table 6.19). Consequently, there is no evidence to suggest an association between group type and presence or not of anxiety or depression.

6.6.6 Health state VAS

Results for both groups were clustered towards the upper end of the scale indicating relatively high self-evaluations of current health state overall (Table 6.18). However, some participants recorded quite low scores resulting in a relatively large degree of negative skew in both groups (Figure 6.19).

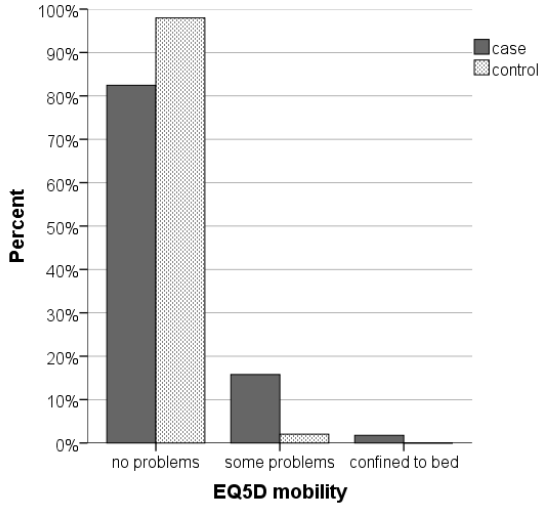
On average, cases reported worse current health states than controls (medians = 85 and 92 respectively). This 7 point difference was statistically significant, resulting in rejection of the null hypothesis of no difference between groups (Mann-Whitney U test, U=3335.50, z=-4.612, p<0.001, r=-0.29) (Table 6.19).

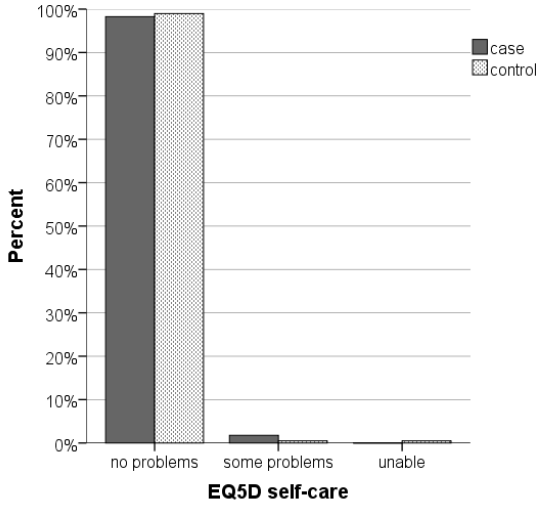
A point-biserial correlation was run to determine the relationship between perceived health state and group type. Group type was significantly related to the health state score (r_{pb} = 0.300; 95% BCa CI 0.164, 0.425; p<0.001) although it shared only 9% of the variability in EQ5D health state score (r_{pb}^2=0.09) (Table 6.19).

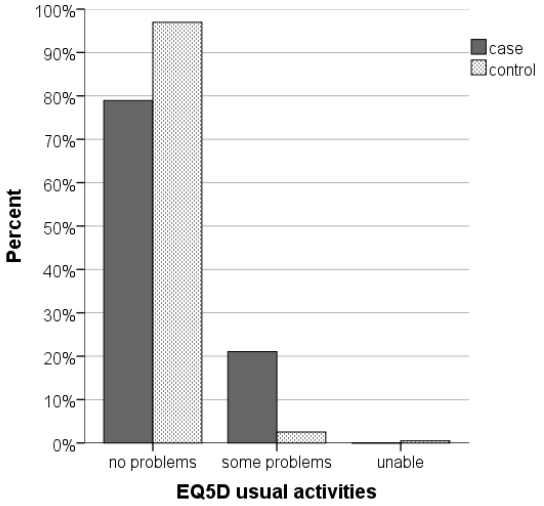
Table 6.16 EQ5D 3L observed counts

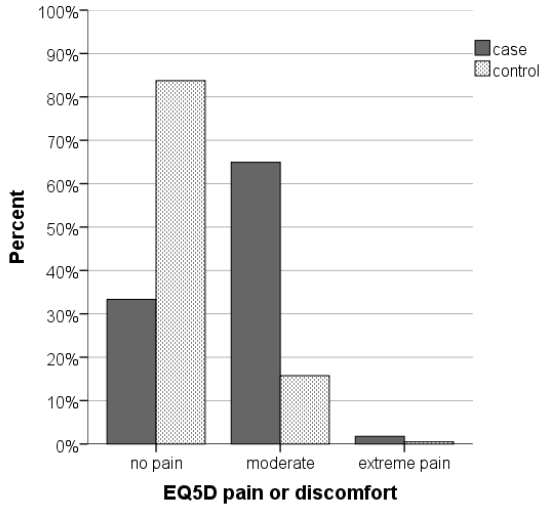
domain	case		control		total	
	n	%	n	%	n	%
mobility						
1 no problems	47	82.5	192	98.0	239	94.5
2 some problems	9	15.8	4	2.0	13	5.1
3 extreme problems	1	1.8	0	0	1	0.4
subtotal	57	100	196	100	253	100
missing	1	1.7	1	0.5	2	0.8
self-care						
1 no problems	56	98.2	194	99.0	250	98.8
2 some problems	1	1.8	1	0.5	2	0.8
3 extreme problems	0	0	1	0.5	1	0.4
subtotal	57	100	196	100	253	100
missing	1	1.7	1	0.5	2	0.8
activity						
1 no problems	45	78.9	191	97.0	236	92.9
2 some problems	12	21.1	5	2.5	17	6.7
3 extreme problems	0	0	1	0.5	1	0.4
subtotal	57	100	197	100	254	100
missing	1	1.7	0	0	1	0.4
pain						
1 no problems	19	33.3	165	83.8	184	72.4
2 some problems	37	64.9	31	15.7	68	26.8
3 extreme problems	1	1.8	1	0.5	2	0.8
subtotal	57	100	197	100	254	100.0
missing	1	1.7	0	0	1	0.4
anxiety						
1 no problems	42	73.7	163	83.2	205	81.0
2 some problems	12	21.1	32	16.3	44	17.4
3 extreme problems	3	5.3	1	0.5	4	1.6
subtotal	57	100	196	100	253	100
missing	1	1.7	1	0.5	2	0.8

Figure 6.18 EQ5D - 3L domains









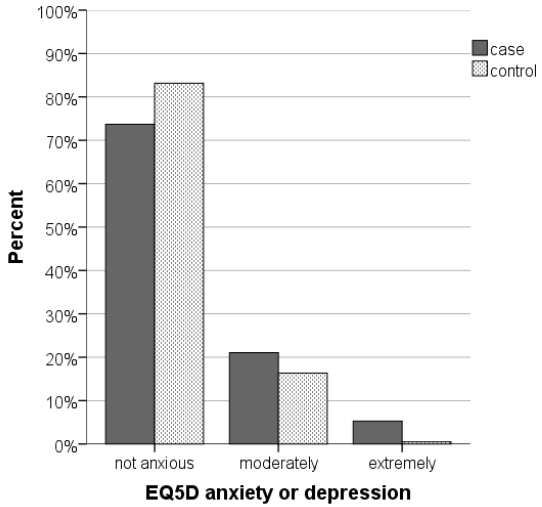


Table 6.17 EQ5D 3L combined problems - expected counts, proportions & odds ratio

domain	case		control		total problem category	case		control		OR
	n (%)	n (%)	n (%)	n (%)		% problem category	odds	% problem category	odds	
mobility*										
no problems	47 (82.5)	53.8 (94.4)	192 (98.0)	185.2 (94.5)	239	19.7	4.7	80.3	48	0.10
problems	10 (17.5)	3.2 (5.6)	4 (2.0)	10.8 (5.5)	14	71.4	0.213	28.6	0.021	10.21
subtotal	57 (100)	57	196 (100)	196	-	-	-	-	-	-
missing	1 (1.7)	-	1 (0.5)	-	-	-	-	-	-	-
self-care										
no problems	56 (98.2)	56.3 (98.8)	194 (99.0)	193.7 (98.8)	250	22.4	56.0	77.6	97	0.58
problems	1 (1.8)	0.7 (1.2)	2 (1.0)	2.3 (1.2)	3	33.3	0.018	66.7	0.01	1.73
subtotal	57 (100)	57	196 (100)	196	-	-	-	-	-	-
missing	1 (1.7)	-	1 (0.5)	-	-	-	-	-	-	-
activity*										
no problems	45 (78.9)	53 (93.0)	191 (97.0)	183 (92.9)	236	19.1	3.75	80.9	31.83	0.12
problems	12 (21.1)	4 (7.0)	6 (3.0)	14 (7.1)	18	66.7	0.267	33.3	0.031	8.49
subtotal	57 (100)	57	197 (100)	197	-	-	-	-	-	-
missing	1 (1.7)	-	0	-	-	-	-	-	-	-
pain*										
no problems	19 (33.3)	41.3 (72.5)	165 (83.8)	142.7 (72.4)	184	10.3	0.50	89.7	5.16	0.10
problems	38 (66.7)	15.7 (27.5)	32 (16.2)	54.3 (27.6)	70	54.3	2.00	45.7	0.194	10.31
subtotal	57 (100)	57	197 (100)	197	-	-	-	-	-	-
missing	1 (1.7)	-	0	-	-	-	-	-	-	-
anxiety										
no problems	42 (73.7)	46.2 (81.1)	163 (83.2)	158.8 (81.0)	205	20.5	2.8	79.5	4.94	0.57
problems	15 (26.3)	10.8 (18.9)	33 (16.8)	37.2 (19.0)	48	31.3	0.357	68.8	0.202	1.76
subtotal	57 (100)	57	196 (100)	196	-	-	-	-	-	-
missing	1 (1.7)	-	1 (0.5)	-	-	-	-	-	-	-

* statistically significant difference between groups

Table 6.18 EQ5D health state descriptive statistics

	n	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
case	57	77.7	19.2	2.54	72.6, 82.7	85.0	68-90	20	100	1 (1.7)
control	197	88.7	13.2	0.94	86.8, 90.5	92.0	85-98	15	100	2 (1.0)

Figure 6.19 EQ5D health state histograms & boxplot

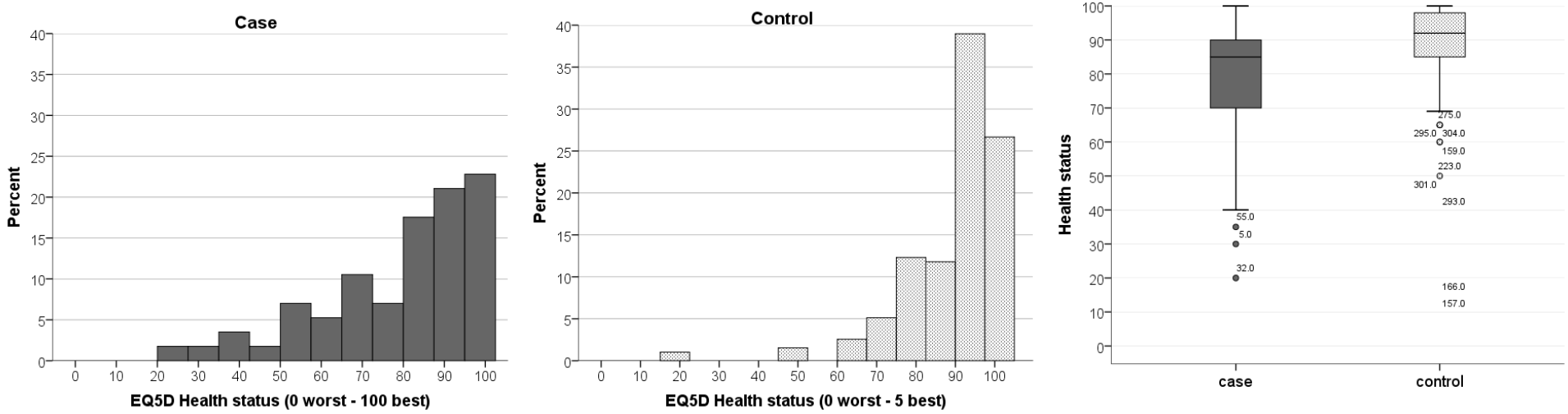


Table 6.19 EQ5D - results of statistical analyses

measure	scale	test	χ^2	df	p-value	OR	95% CI	z	p-value
EQ5D	mobility	Fisher's exact	20.30	1	<0.001*	10.21	3.1, 34.0	3.79	0.0002*
	self care	Fisher's exact	0.203	1	0.537	1.73	0.15, 19.5	0.445	0.656
	activity	Fisher's exact	21.77	1	<0.001*	8.49	3.0, 23.8	4.06	<0.001*
	pain	chi-square	56.30	1	<0.001*	10.31	5.3, 20.1	6.84	<0.001*
	anxiety	Fisher's exact	2.58	1	0.125	1.76	0.88, 3.55	1.59	0.111

measure	scale	test	group	diff medians	U	z	p-value	effect size**	r_{pb}	95% BCa CI	r_{pb}^2
EQ5D	health state VAS	Mann-Whitney U	case v control	-7	3335.5	-4.612	<0.001*	-0.29	0.300*	0.164, 0.425	0.09

* statistically significant; ** Pearson's r

6.7 Paediatric Outcomes Data Collection Instrument (PODCI)

6.7.1 Upper extremity and physical function

Both case and control participants scored highly on this scale with a high percentage in each group recording maximum scores, indicating no difficulties with basic upper limb tasks (Figure 6.20).

The median score for both groups was 100 (Table 6.20). Despite this, a statistically significant difference was revealed between the two groups in favour of the control group (Mann-Whitney U test, U=4515.50, z=-2.668, p=0.007, r=-0.17).

A point-biserial correlation was run to determine the relationship between upper limb function and group type. Group type was significantly related to the upper limb function score (r_{pb} = 0.187; 95% BCa CI 0.062, 0.310; p=0.003) although it shared only 3.5% of the variability in PODCI upper extremity and physical function score (r_{pb}^2=0.035) (Table 6.21).

6.7.2 Transfers and basic mobility

Results for this scale mimic those for the upper extremity scale with the majority of participants in both groups recording maximum scores (Figure 6.21 and Table 6.20). Again, median scores were 100 although a statistically significant difference was calculated in favour of the control group (Mann-Whitney U test, U=4354.00, z=-3.562, p<0.001, r=-0.22).

A point-biserial correlation was run to determine the relationship between transfers/mobility and group type. Group type was significantly related to the transfers/mobility score (r_{pb} = 0.165; 95% BCa CI 0.04, 0.35; p=0.008) although it shared only 2.7% of the variability in PODCI transfers and basic mobility score (r_{pb}^2=0.027) (Table 6.21).

6.7.3 Sports and physical functioning

Control participants scored in a similar manner to previous scales of PODCI with a heavy concentration of scores at the upper end of the scale indicating little or no difficulty with sporting activities. Case participants were slightly less skewed and this was reflected in lower mean and median scores (Figure 6.22 and Table 6.20).

The 5.5 point difference between cases and controls was statistically significant (median values = 91.67 and 97.22 respectively; U=3966.00, z=-3.49, p<0.001, r=-0.22) suggesting cases were slightly less able than controls with regard to sporting activities.

A point-biserial correlation was run to determine the relationship between sports function and group type. Group type was significantly related to the sports function score (r_{pb} = 0.240; 95% BCa CI 0.10, 0.385; p<0.001) although it shared only 5.8% of the variability in PODCI sports and physical functioning score (r_{pb}^2=0.058) (Table 6.21).

6.7.4 Pain/comfort

Although most participants scored relatively highly on this scale, the distribution was spread more evenly particularly amongst cases (Figure 6.23 and Table 6.20). This indicates that a sizeable proportion of participants reported some pain or pain-related disability.

The difference between groups was much larger than in other PODCI scales with cases describing significantly worse pain/comfort scores than controls (median values = 78.33 and 100 respectively; Mann-Whitney U-test; U=3418.00, z=-4.712, p<0.001, r=-0.30).

A point-biserial correlation was run to determine the relationship between pain and group type. Group type was significantly related to the pain score (r_{pb} = 0.296; 95% BCa CI 0.158, 0.423; p<0.001) although it shared only 8.8% of the variability in PODCI pain and comfort score (r_{pb}^2=0.088) (Table 6.21).

6.7.5 Global function

Combining scores from the previous four scales produced similar results with scores for control participants heavily skewed towards the maximum indicating better function (Figure 6.24). Case participants, although scoring highly, were less skewed with consequent lower mean and median scores (Table 6.20).

A 5.8 point difference in median scores between the case and controls was statistically significant (median values = 91.39 and 97.2 respectively; U=3498.00, z=-4.347, p<0.001, r=-0.27) indicating that cases had worse functional outcomes.

A point-biserial correlation was run to determine the relationship between global function and group type. Group type was significantly related to the global function score (r_{pb} = 0.336; 95%

BCa CI 0.185, 0.474; p<0.001) although it shared only 11.3% of the variability in PODCI global function score (r_{pb}^2=0.113) (Table 6.21).

6.7.6 Happiness

Figure 6.25 illustrates the spread of scores for cases and controls on the happiness with physical condition scale. Although median scores for both groups were relatively high, indicating high average levels of happiness, the range of scores was very wide particularly amongst cases (0-100).

There was a 10 point difference in median scores between groups suggesting that on average, cases were less happy than controls (Table 6.20). This difference was statistically significant (median values = 80 and 90 cases/controls respectively; U=3983.00, z=-3.39, p=0.001, r=-0.21).

A point-biserial correlation was run to determine the relationship between happiness and group type. Group type was significantly related to the happiness score (r_{pb} = 0.286; 95% BCa CI 0.141, 0.417; p<0.001) although it shared only 8.2% of the variability in PODCI happiness score (r_{pb}^2=0.082) (Table 6.21).

Table 6.20 PODCI scores

scale (0 worst - 100 best)	group	n	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
upper extremity & physical function	case	57	95.3	8.39	1.11	93.0, 97.5	100	93.8, 100	50.0	100	1 (1.7)
	control	197	97.8	4.66	0.33	97.2, 98.5	100	95.8, 100	62.5	100	0
transfers & basic mobility	case	57	97.8	3.93	0.52	96.7, 98.8	100	97, 100	79.6	100	1 (1.7)
	control	197	99.1	3.2	0.23	98.7, 99.6	100	100, 100	69.7	100	0
sports & physical function	case	57	88.9	12.8	1.69	85.5, 92.3	91.7	84, 100	45.1	100	1 (1.7)
	control	197	94.7	8.72	0.62	93.4, 95.9	97.2	93.1, 100	36.1	100	0
pain & comfort	case	57	77.4	19.1	2.53	72.3, 82.5	78.3	65, 93.3	32.8	100	1 (1.7)
	control	197	89.4	15.2	1.09	87.2, 91.5	100	82.2, 100	15.0	100	0
global function	case	57	89.8	9.04	1.20	87.4, 92.2	91.4	83, 97.6	58.4	100	1 (1.7)
	control	197	95.3	5.37	0.38	94.5, 96.0	97.2	92.5, 99	62.0	100	0
happiness	case	57	73.1	25.6	3.39	66.3, 79.9	80.0	55, 95	0	100	1 (1.7)
	control	197	86.0	15.3	1.09	83.8, 88.1	90.0	80, 100	25.0	100	0

Figure 6.20 PODCI upper extremity & physical function - histogram & boxplot

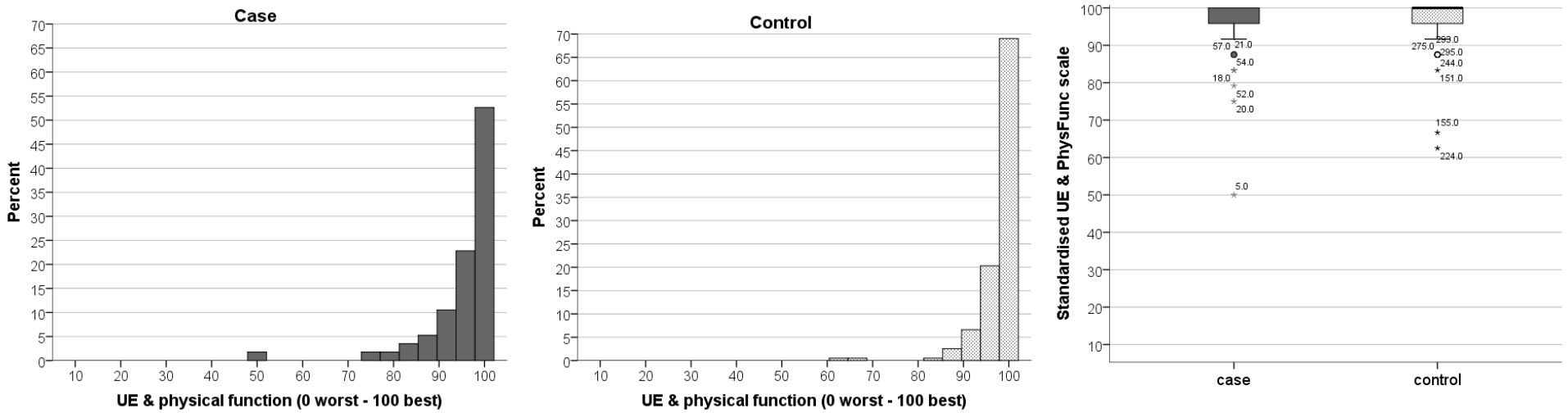


Figure 6.21 PODCI transfers & basic mobility - histogram & box plot

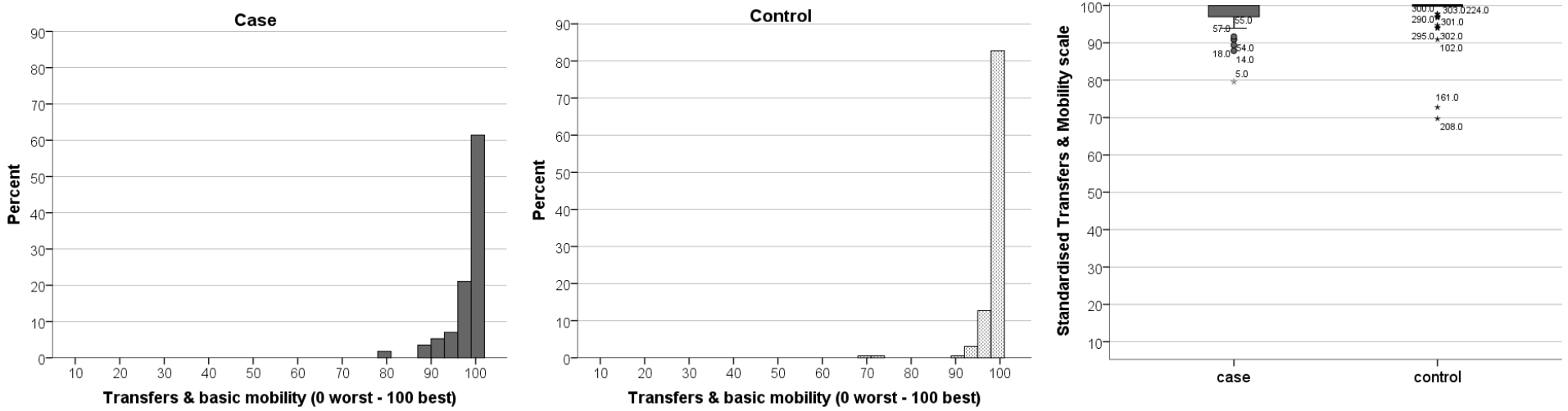


Figure 6.22 PODCI sports & physical functioning - histogram & boxplot

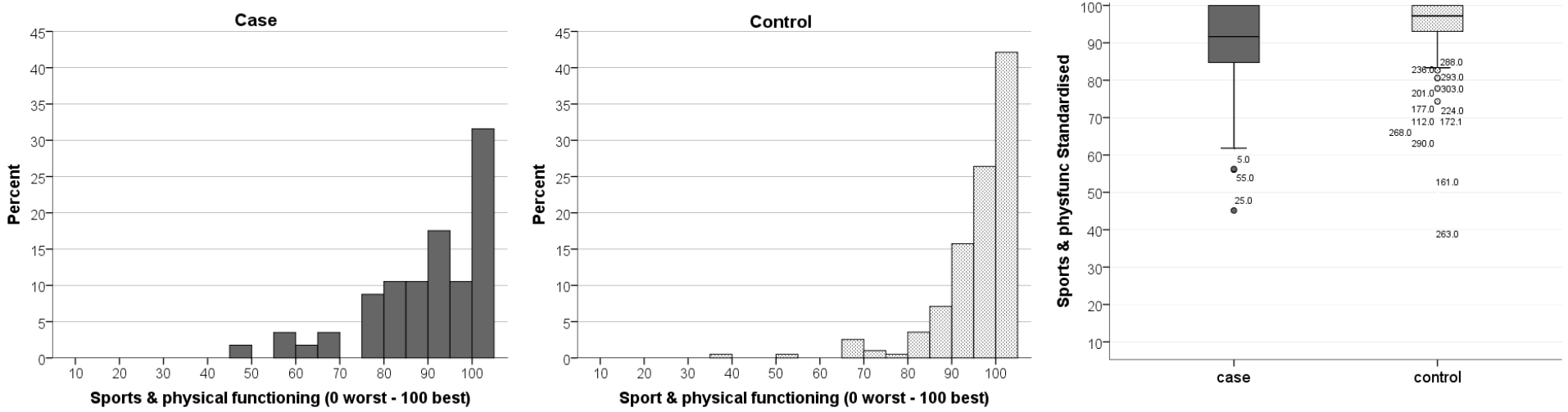


Figure 6.23 PODCI pain/comfort - histogram & boxplot

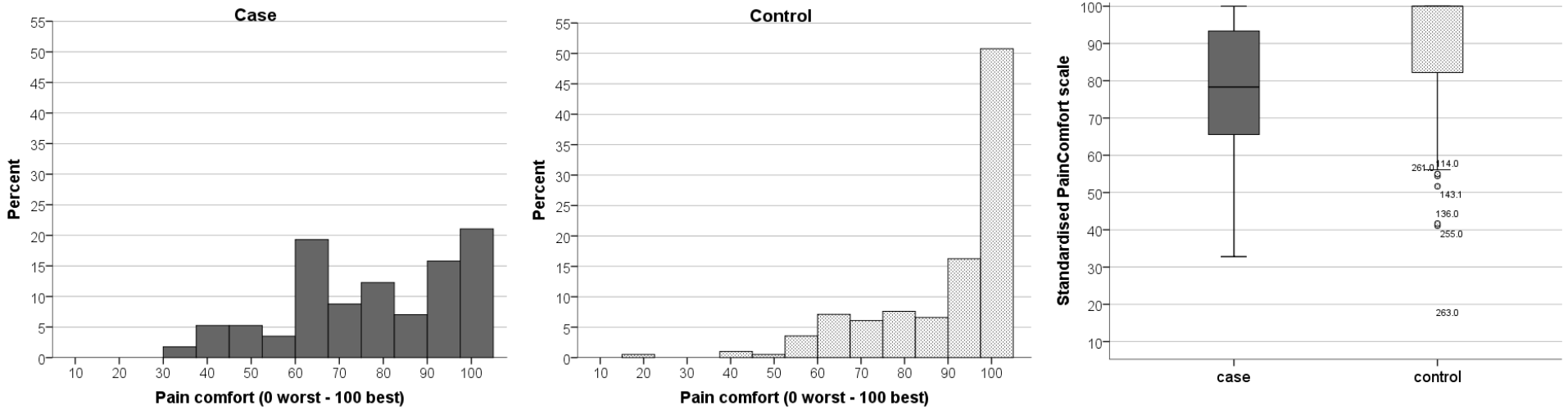


Figure 6.24 PODCI global function - histogram & boxplot

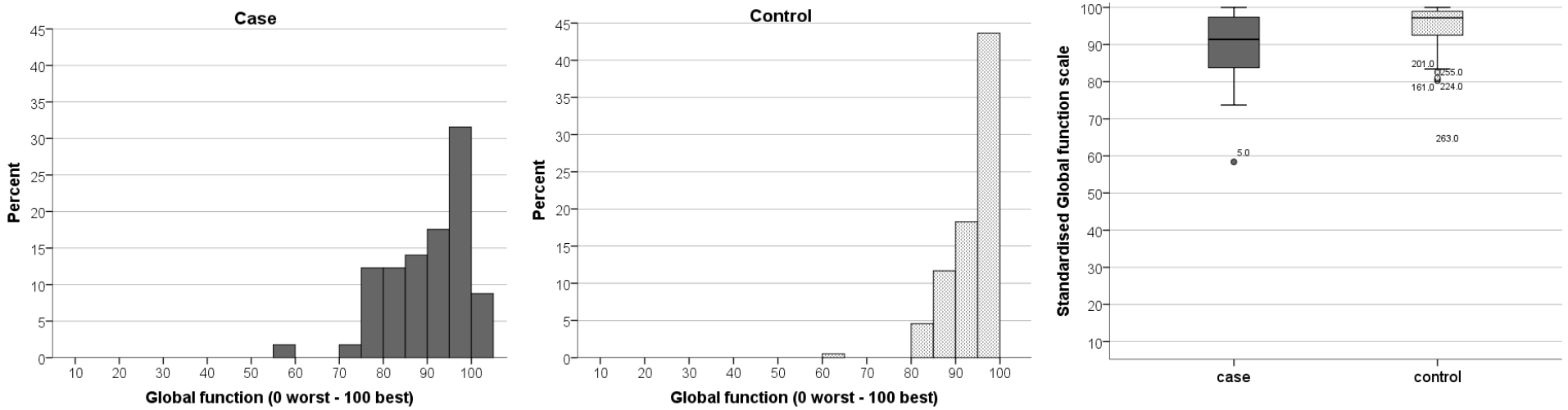


Figure 6.25 PODCI happiness with physical condition - histogram & boxplot

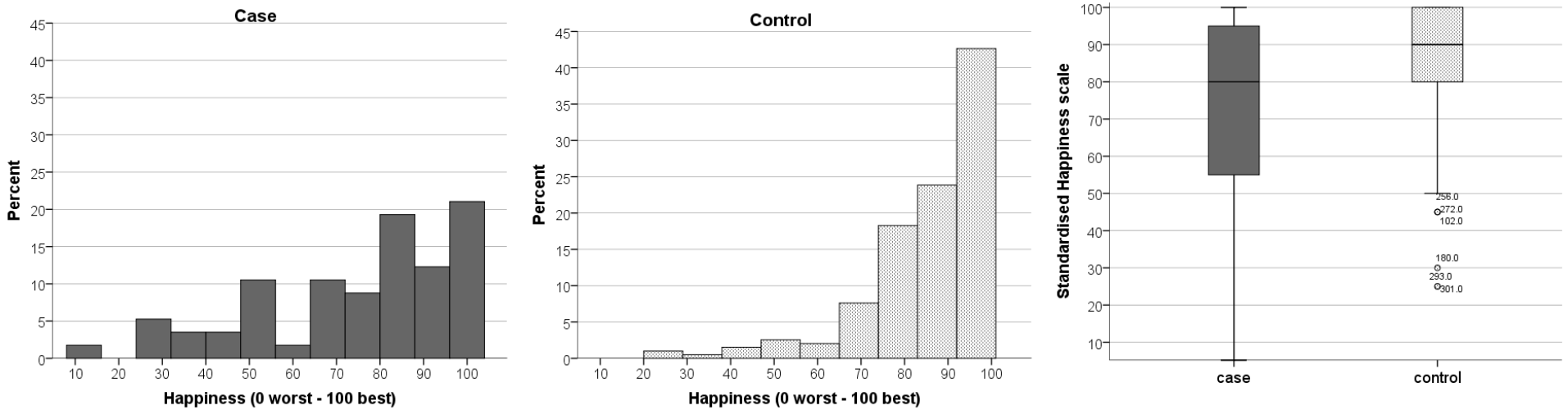


Table 6.21 PODCI - results of statistical analyses

measure	scale	test	group	diff medians	U	z	p-value	effect size**	r_{pb}	95% BCa CI	r_{pb}^2
PODCI	UE & PhysFunc	Mann-Whitney U	case v control	0	4515.5	-2.67	0.007*	-0.17	0.187*	0.06, 0.31	0.035
	Transfers &mobility	Mann-Whitney U	case v control	0	4354.0	-3.56	<0.001*	-0.22	0.165*	0.04, 0.35	0.027
	Sports & PhysFunc	Mann-Whitney U	case v control	5.5	3966.0	-3.49	<0.001*	-0.22	0.240*	0.099, 0.385	0.058
	Pain	Mann-Whitney U	case v control	21.67	3418.0	-4.71	<0.001*	-0.30	0.296*	0.158, 0.423	0.088
	Global function	Mann-Whitney U	case v control	5.8	3498	-4.35	<0.001*	-0.27	0.336*	0.185, 0.474	0.113
	Happiness	Mann-Whitney U	case v control	10	3983	-3.39	0.001*	-0.21	0.286*	0.141, 0.417	0.082

* statistically significant; ** Pearson's r

6.8 Two point discrimination

Two-point discrimination threshold (TPDT) testing involved assessment of both the left and right side of the spine. For cases, testing took place to either side of the vertebral level corresponding to the curve apex of the primary curve. For controls, testing was at the same vertebral level as their matching cases.

For some participants, it was not possible to determine the TPDT for either one or both sides. This resulted in 6 case participants missing data for both sides, 2 missing data for the left side only and 2 for the right side. One control participant was missing data for the left side and another for the right side only.

Within-group analyses of left versus right and affected versus unaffected side were performed along with a between-group analysis of case versus control participants. Lower TPDTs (measured in mm) indicate greater sensitivity and tactile acuity.

6.8.1 Left v Right

Descriptive statistics and distributions are provided in

Table 6.22 and Figure 6.26 to Figure 6.27. Statistical analysis of the difference between left and right TPDT thresholds within each group was conducted with a paired-samples t-test (Table 6.23).

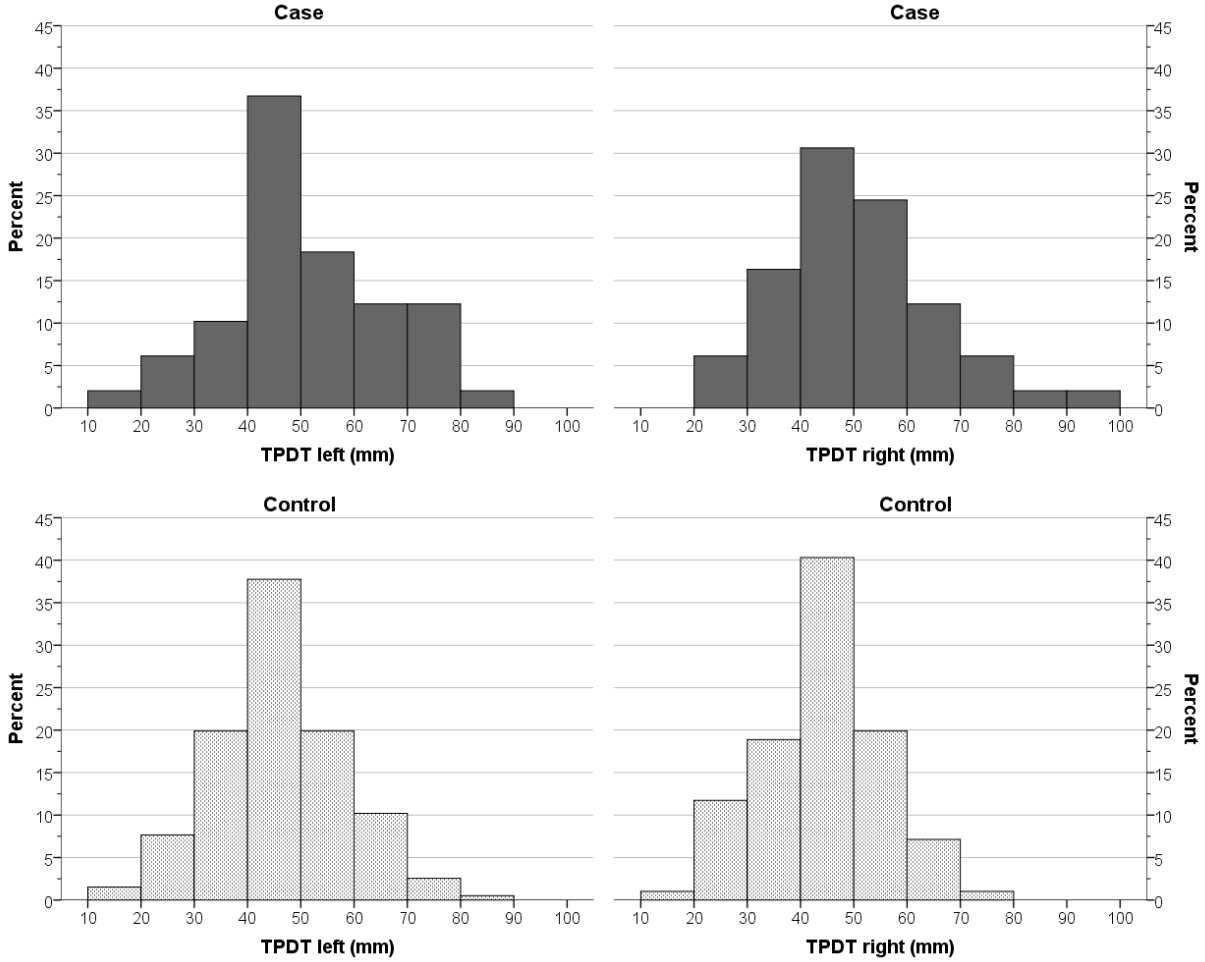
For cases, on average, there was little difference in TPD thresholds between tests performed on the left and right side of the spine (mean = 49.2 mm and 48.6 mm respectively) and this difference was not statistically significant (mean difference = 1.38 mm; 95% CI -3.11, 5.88; t = 0.62; DF = 46; p = 0.54; *d* = 0.09).

Similarly for controls, on average there was little difference between tests performed on the left and right sides (mean = 43.3 mm and 41.4 mm respectively). However, this difference was statistically significant (mean difference = 1.97 mm; 95% CI 0.33, 3.62; t = 2.37; DF = 195; p = 0.019; *d* = 0.17).

Table 6.22 Two-point discrimination threshold descriptive statistics - Left v Right within groups (mm)

	side	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=49)	L	49.18	15.72	2.25	44.67, 53.70	45.00	40, 60	10.00	80.00	9
	R	48.57	14.79	2.11	44.32, 52.82	45.00	40, 55	25.00	90.00	
control (n=196)	L	43.32	11.77	0.84	41.66, 44.97	45.00	35, 50	15.00	80.00	1
	R	41.35	11.22	0.80	39.77, 42.93	40.00	35, 50	15.00	75.00	

Figure 6.26 Two point discrimination threshold histograms & boxplots - Left v Right within groups



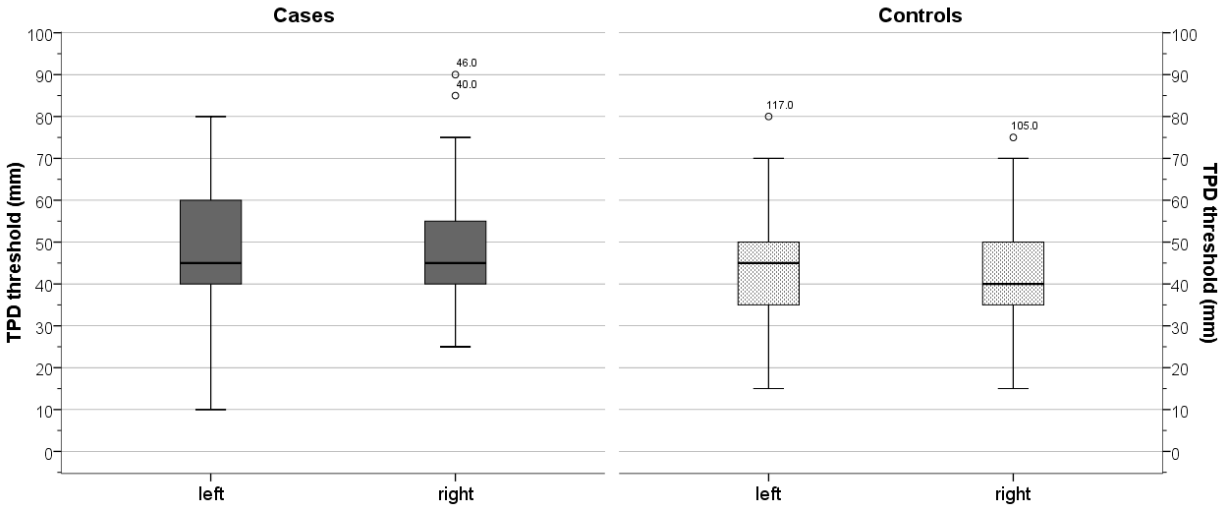


Figure 6.27 Two point discrimination threshold means (95% CI) - Left v Right within groups

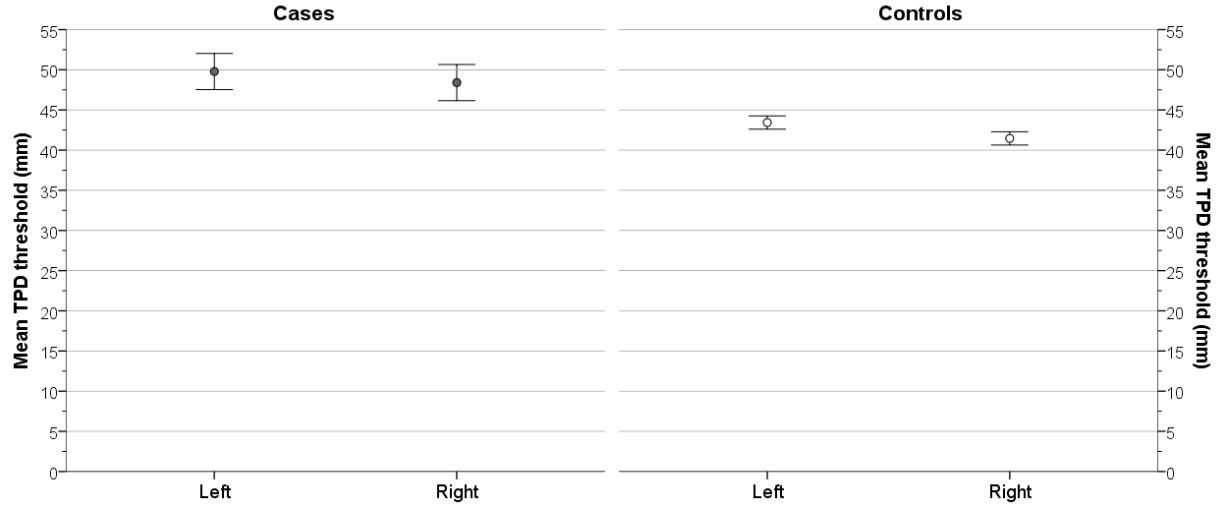


Table 6.23 TPDT Left v Right - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Left v Right	paired t-test	case	1.38	-3.11, 5.88	0.62	46	0.539	0.09
		control	1.97	0.33, 3.62	2.37	194	0.019*	0.17

* = statistically significant

6.8.2 Affected v Unaffected side

Descriptive statistics for Affected and Unaffected side are described in Table 6.24 and illustrated in Figure 6.28 and Figure 6.29. One case was missing x-ray information so was unable to be categorised according to curve direction, along with the 3 matched control participants.

Statistical analysis of the difference between Affected and Unaffected TPD thresholds within each group was conducted with a paired-samples t-test (Table 6.25).

For cases, on average, there was little difference in TPDTs between tests conducted on the affected or unaffected side (mean = 47.9 mm and 49.9 mm respectively) and this difference was not statistically significant (mean difference = -2.02 mm; 95% CI -6.50, 2.45; t = -0.91; DF = 46; p = 0.368; *d* = -0.13).

Similarly for controls, on average there was little difference between tests performed on the affected or unaffected side (mean = 41.3 mm and 43.4 mm respectively). However, this difference was statistically significant (mean difference = -2.11 mm; 95% CI -3.77, -0.45; t = -2.51; DF = 191; p = -0.013; *d* = -0.19).

Table 6.24 Two point discrimination threshold descriptive statistics- Affected v Unaffected side within groups

	side	n	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case	A	50	47.9	14.95	2.11	43.7, 52.2	45.0	40, 55	10.0	90.0	8
	U	48	49.9	15.52	2.24	45.4, 54.4	45.0	40, 64	20.0	85.0	10
control	A	193	41.3	11.81	0.85	39.6, 43.0	40.0	35, 50	15.0	70.0	4
	U	193	43.4	11.29	0.81	41.8, 45.0	45.0	35, 50	15.0	80.0	4

Figure 6.28 Two point discrimination threshold histograms & boxplots - Affected v Unaffected side within groups

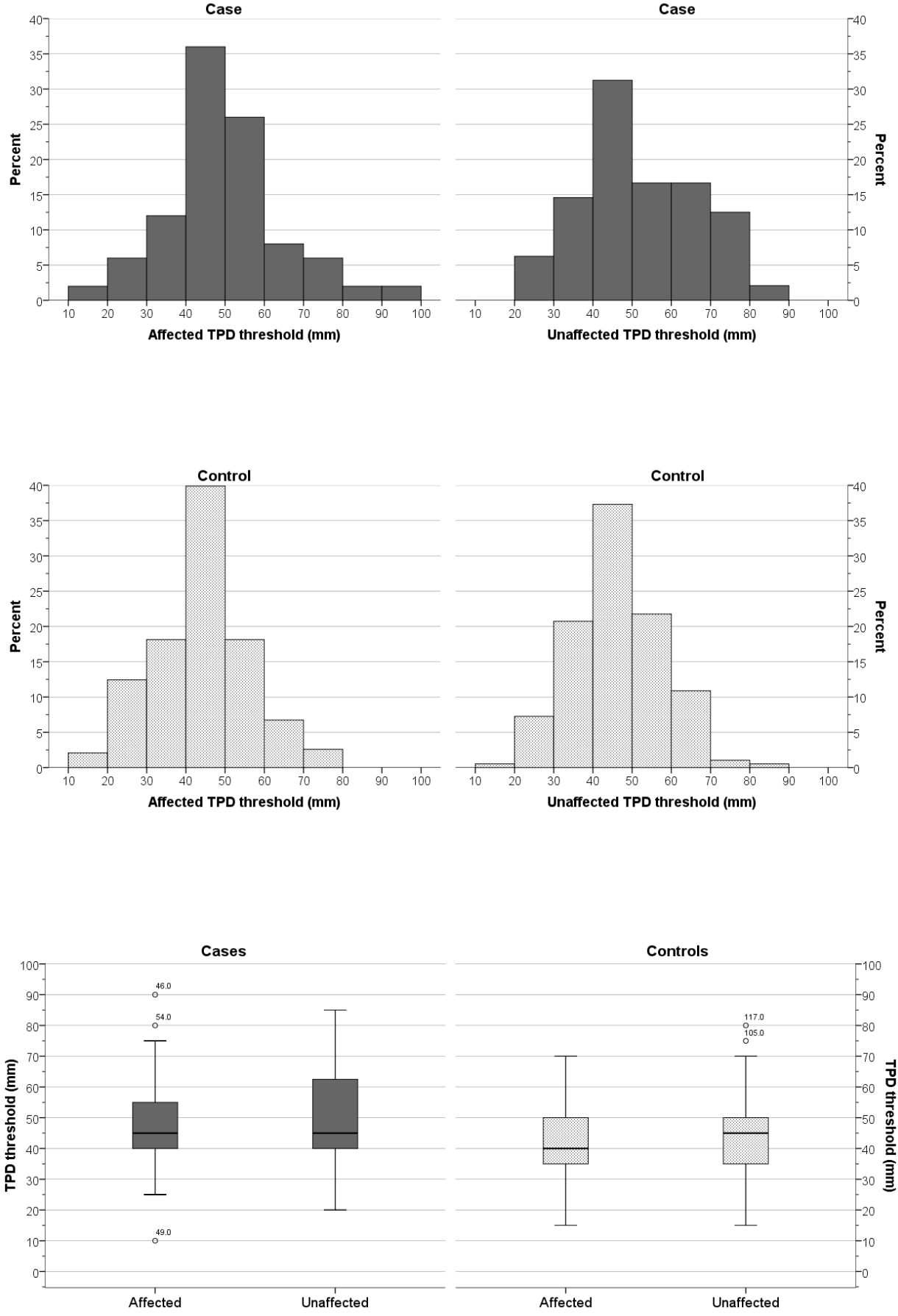


Figure 6.29 Two point discrimination threshold means (95% CI) - Affected v Unaffected

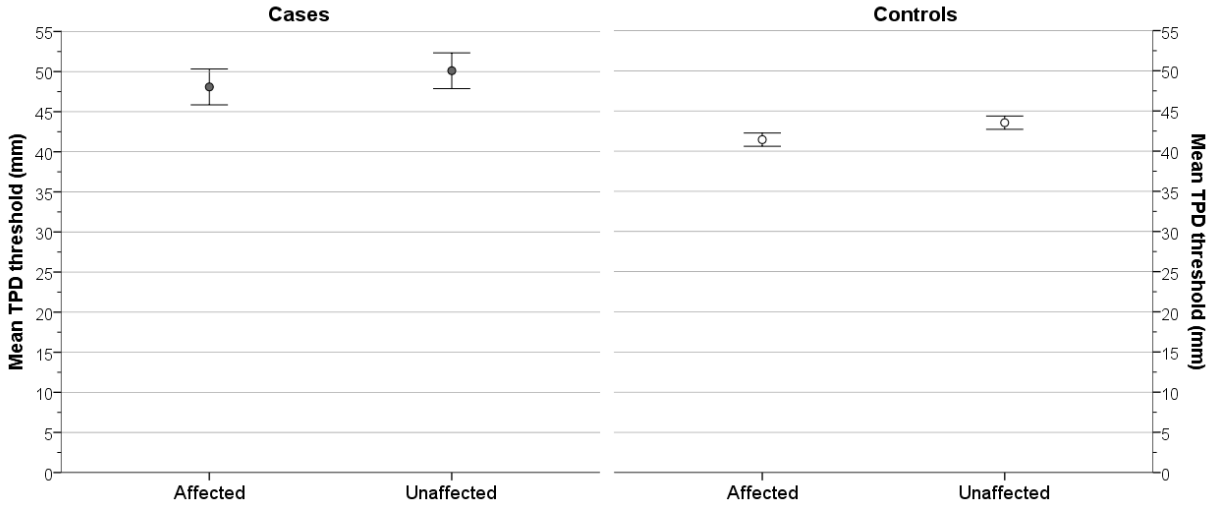


Table 6.25 TPDT Affected v Unaffected - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Affected v unaffected	paired t-test	case	-2.02	-6.50, 2.45	-0.91	46	0.368	-0.13
		control	-2.11	-3.77, -0.45	-2.51	191	0.013*	-0.19

* = statistically significant

6.8.3 Case v Control

As the differences in TPDT within groups (left v right, affected v unaffected sides) was small and generally not statistically significant, trials were combined to form one Case and one Control variable allowing for a direct comparison between the two groups (Table 6.26 and Figure 6.30). An independent-samples t-test was used to test the statistical significance of the difference between groups (Table 6.27).

On average, the mean difference in TPDT between case and control participants was small (means = 49.1 mm and 42.5 mm respectively) although this difference was statistically significant (difference in means = 6.65 mm; 95% CI 2.53, 10.76; t = 3.23; df = 58.74; p = 0.002; *d* = 0.68).

A point-biserial correlation was run to determine the relationship between TPDT and group type. Group type was significantly related to the TPDT (r_{pb} = 0.242; 95% BCa CI 0.096, 0.383; p<0.001) although it shared only 5.9% of the variability in TPDT (r_{pb}^2=0.059) (Table 6.28).

Table 6.26 Two point discrimination threshold - Case v Control between groups

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)	missing %
case (n=47)	49.10	13.25	1.93	45.2, 53.0	47.50	38, 60	27.5	75.0	11	19.0
control (n=195)	42.45	9.82	0.70	41.1, 43.8	42.50	35, 50	15.0	70.0	2	1.0

Figure 6.30 Two point discrimination threshold - histograms, boxplots & means (95% CI) Case v Control

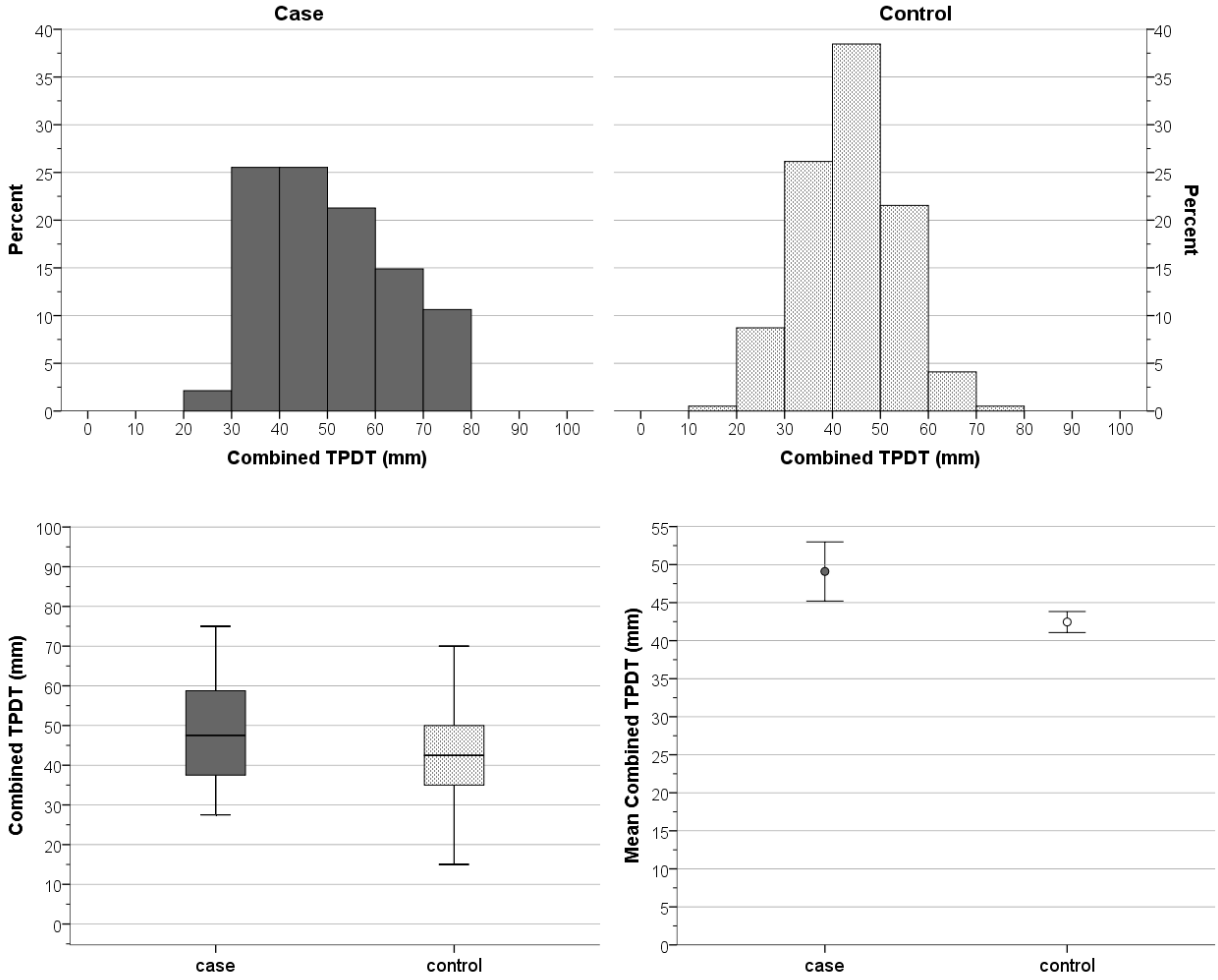


Table 6.27 Two-point discrimination threshold - Results of statistical analyses

analysis	test	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	6.65	2.53, 10.76	3.230	59	0.002*	0.68

Table 6.28 Correlation between TPDT and group - case control

analysis	test	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	0.242	0.096, 0.383	0.059	<0.001*

* statistically significant

6.9 Localisation

6.9.1 Left v Right

Descriptive statistics and distributions are provided in Table 6.29 and Figure 6.31 to Figure 6.32. Statistical analysis of the difference between left and right localisation accuracy within each group was conducted with a paired-samples t-test (Table 6.30).

For cases, on average, there was little difference in localisation accuracy between tests performed on the left and right side of the spine (mean number correct = 5.75, 47.9%; and 5.82, 48.5% respectively) and this difference was not statistically significant (mean difference = -0.07, -0.6%; 95% CI -0.71, 0.57; t = -0.22; DF = 56; p = 0.83; *d* = -0.03).

Similarly for controls, on average there was little difference between tests performed on the left and right sides (mean number correct = 6.46, 53.8%; and 6.47, 53.9% respectively) and this difference was also not statistically significant (mean difference = -0.01, 0.08%; 95% CI -0.33, 0.32; t = -0.03; DF = 196; p = 0.98; *d* = -0.002).

Table 6.29 Localisation descriptive statistics - Left v Right (number correct; max = 12)

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=57)	L	5.75	2.00	0.27	5.22, 6.29	6.00	5, 7	0	9	1 (1.7)
	R	5.82	2.09	0.28	5.27, 6.38	6.00	5, 7	1	10	
control (n=197)	L	6.46	2.40	0.17	6.12, 6.80	7.00	5, 8	0	12	0
	R	6.47	2.39	0.17	6.13, 6.80	6.00	5, 8.5	1	12	

Figure 6.31 Localisation histograms & boxplots - Left v Right within groups

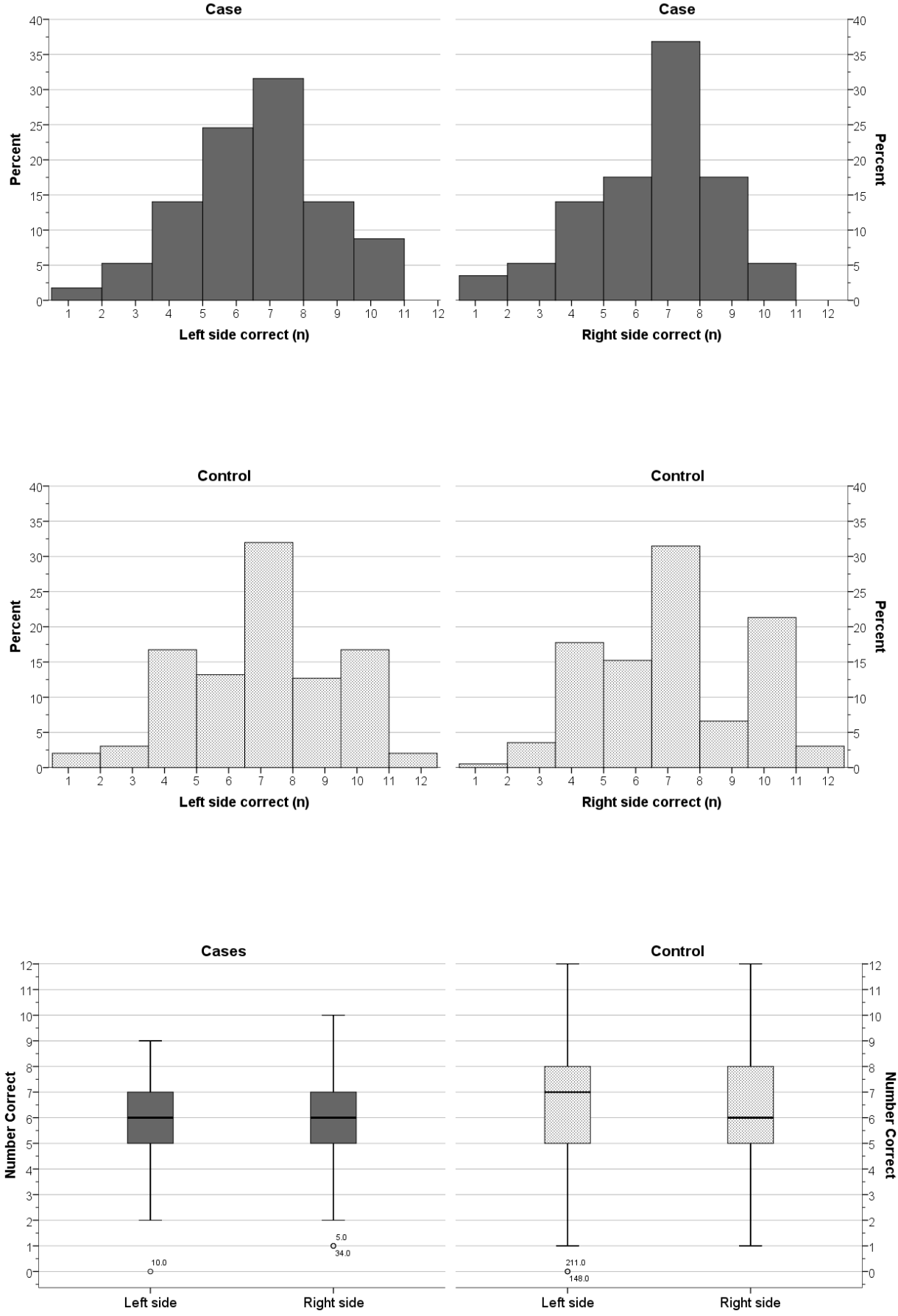


Figure 6.32 Localisation means (95% CI) - Left v Right

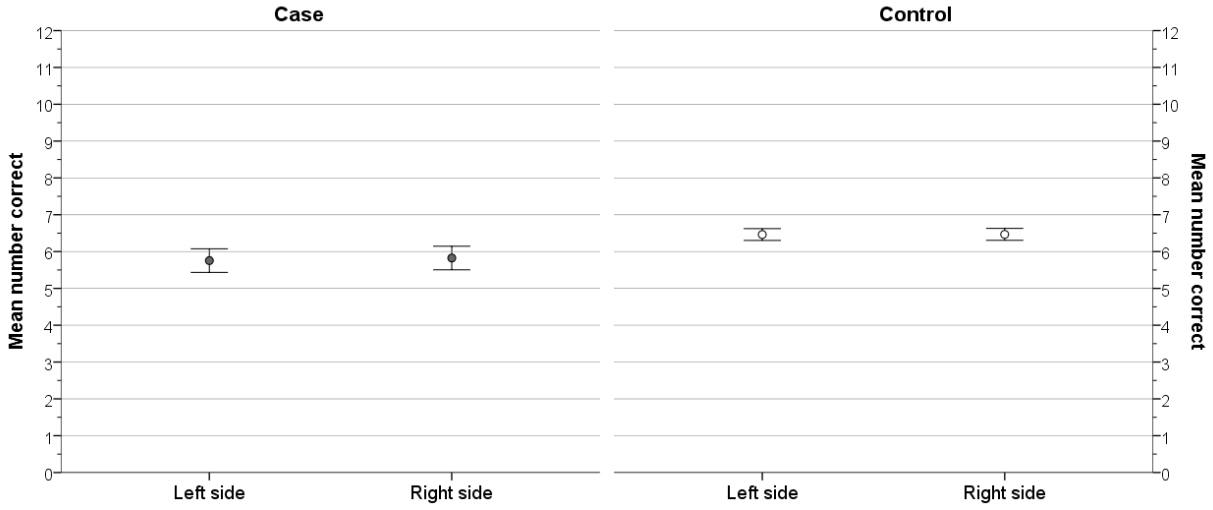


Table 6.30 Localisation Left v Right - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Left v Right	paired t-test	case	-0.07	-0.71, 0.57	-0.22	56	0.827	-0.03
		control	-0.01	-0.33, 0.32	-0.03	196	0.975	-0.002

6.9.2 Affected v Unaffected

Descriptive statistics for Affected and Unaffected side are described in Table 6.31 and Figure 6.33 and Figure 6.34. One case was missing x-ray information so was unable to be categorised according to curve direction, along with the 3 matched control participants.

Statistical analysis of the difference between Affected and Unaffected localisation accuracy within each group was conducted with a paired-samples t-test (Table 6.32).

For cases, on average, there was little difference in localisation accuracy between tests conducted on the affected or unaffected side (mean number correct = 5.91, 49.3%; and 5.75, 47.9% respectively) and this difference was not statistically significant (mean difference = 0.16, 1.3%; 95% CI -0.48, 0.80; t = 0.50; DF = 55; p = 0.62; *d* = 0.08).

Similarly for controls, on average there was little difference between tests performed on the affected or unaffected side (mean number correct = 6.48, 54%; and 6.44, 54% respectively) and this difference was also not statistically significant (mean difference = 0.04, 0.33%; 95% CI -0.28, 0.36; t = 0.25; DF = 193; p = 0.80; *d* = 0.02).

Table 6.31 Localisation descriptive statistics - Affected v Unaffected side

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
case (n=56)	A	5.91	2.01	0.27	5.4, 6.5	6.00	5, 7.8	1	10	2 (3.4)
	U	5.75	2.05	0.27	5.2, 6.3	6.00	5, 7	0	9	2 (3.4)
control (n=194)	A	6.48	2.38	0.17	6.1, 6.8	6.00	5, 8	0	12	3 (1.5)
	U	6.44	2.41	0.17	6.1, 6.8	7.00	5, 8	1	12	3 (1.5)

Figure 6.33 Localisation histogram & boxplots - Affected - Unaffected side

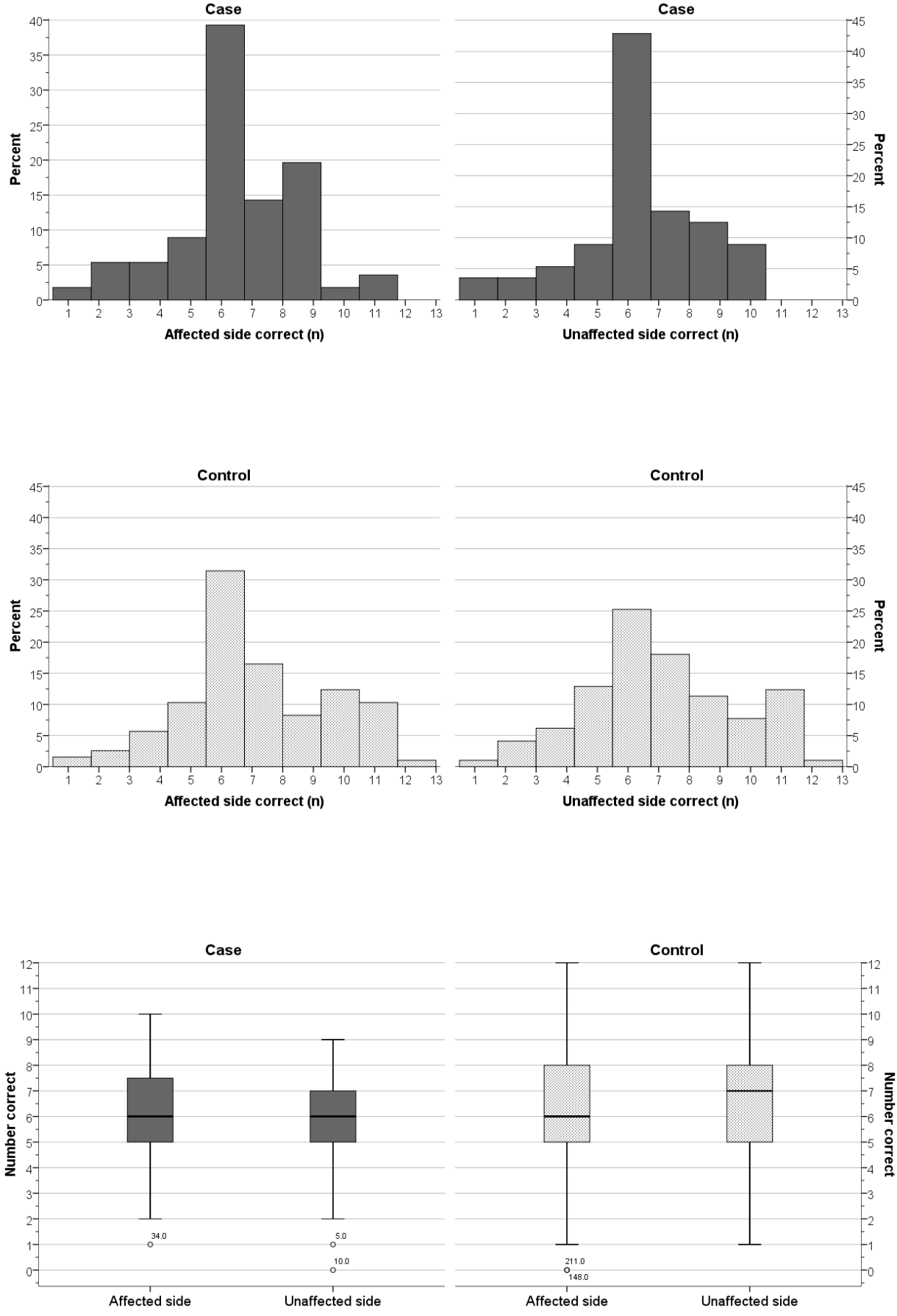


Figure 6.34 Localisation means (95% CI) - Affected v Unaffected side

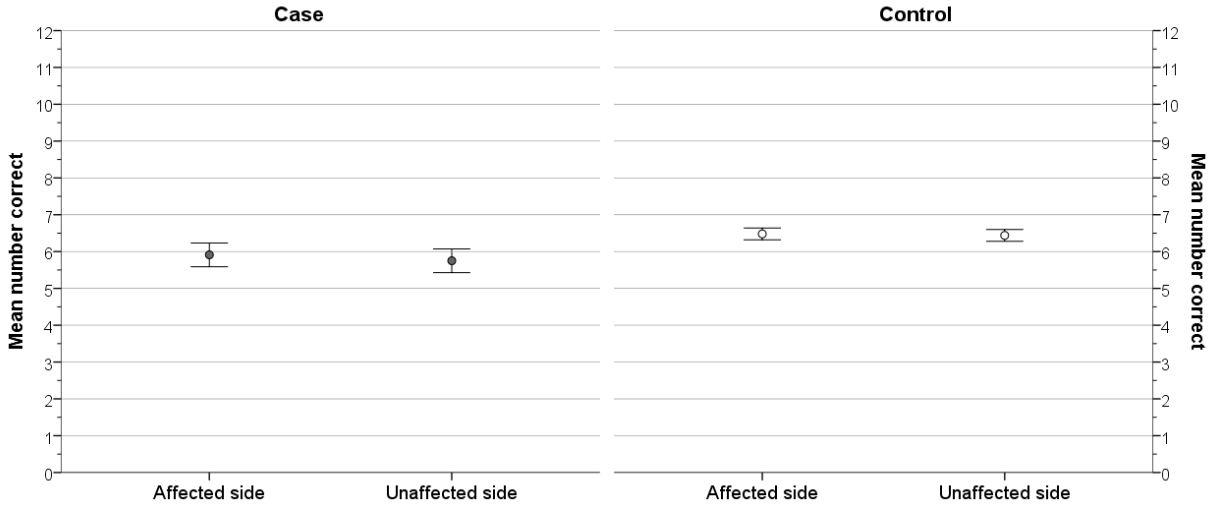


Table 6.32 Localisation Affected v Unaffected - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Affected v unaffected	paired t-test	case	0.16	-0.48, 0.80	0.50	55	0.619	0.08
		control	0.04	-0.28, 0.36	0.25	193	0.800	0.02

6.9.3 Case v Control

As the differences in localisation accuracy within groups (left v right, affected v unaffected sides) was small and generally not statistically significant, trials were combined to form one Case and one Control variable allowing for a direct comparison between the two groups. This comparison also included the 3 central stimulation sites bringing the total number of tests to 30 for each participant.

The distribution of both groups was consistent with a normal distribution (Table 6.33 and Figure 6.35). An independent-samples t-test was used to test the statistical significance of the difference between groups (Table 6.34).

On average, the mean difference in localisation accuracy between case and control participants was small (mean number correct = 14.21, 47.4%; and 16.28, 54.3% respectively) although this difference was statistically significant (difference in means = -2.07, 6.9%; 95% CI -3.49, -0.65; t = -2.87; df = 252; p = 0.004; *d* = -0.43) suggesting that control participants were slightly more accurate on average than case participants.

A point-biserial correlation was run to determine the relationship between localisation ability and group type. Group type was significantly related to the localisation accuracy (r_{pb} = 0.178; 95% BCa CI 0.07, 0.28; p=0.004) although it shared only 3.2% of the variability in accuracy (r_{pb}^2=0.032) (Table 6.35).

Table 6.33 Localisation descriptive statistics - Case v Control location (max=30)

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=57)	14.21	4.52	0.60	13.01, 15.41	15.00	11, 18	4.0	25.0	1 (1.7)
control (n=197)	16.28	4.86	0.35	15.60, 16.96	17.00	13, 20	4.0	29.0	0

Figure 6.35 Localisation histograms, boxplots & means (95% CI) - Case v Control location

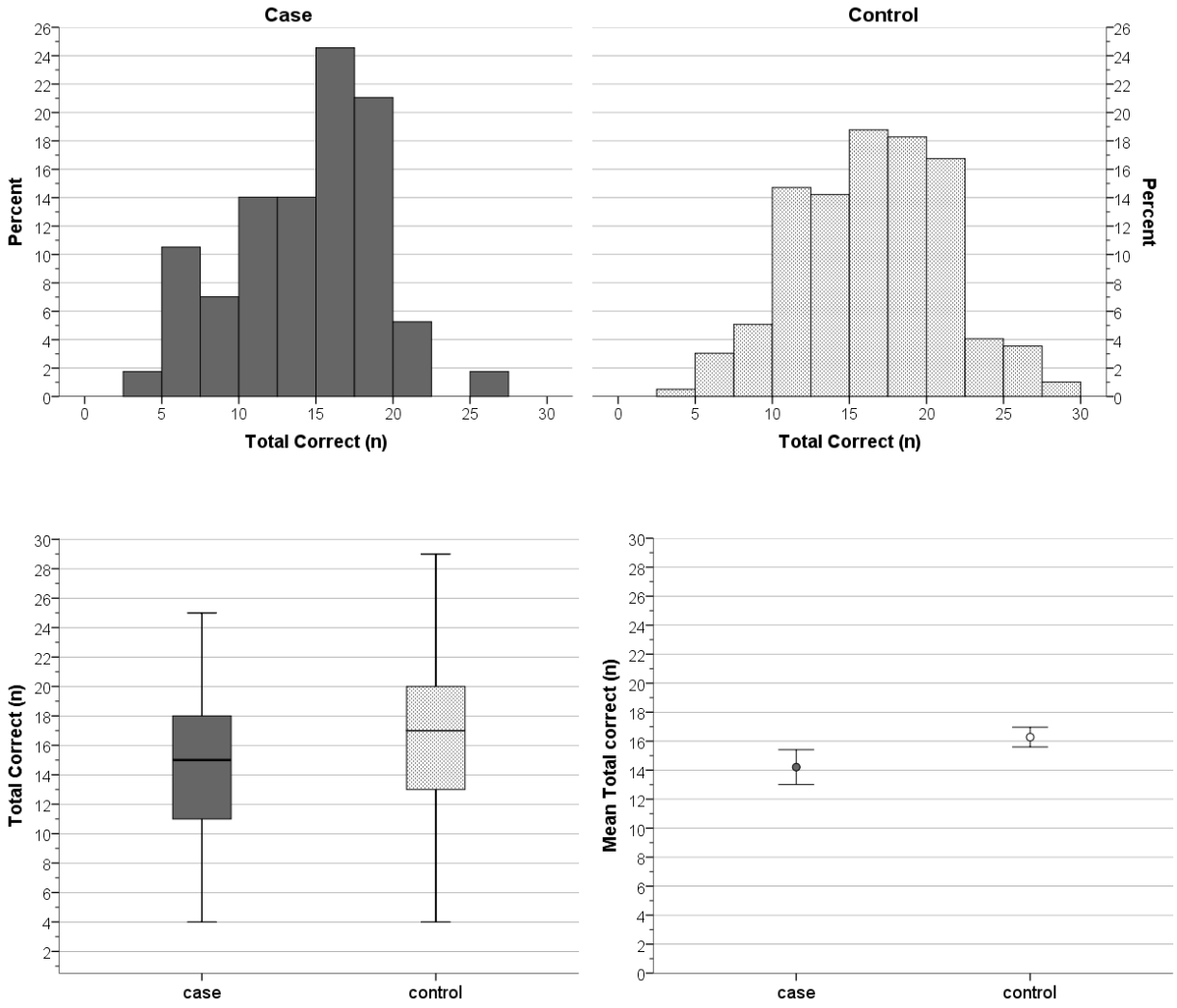


Table 6.34 Localisation Case v Control - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	location	-2.07	-3.49, -0.65	-2.87	252	0.004*	-0.43

* = statistically significant

Table 6.35 Correlation Group type v Localisation accuracy

analysis	test	location	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	individual sites	0.178	0.070, 0.280	0.032	0.004*

* statistically significant

Further analysis was also undertaken to ascertain if participants were able to at least locate the region the stimulus was applied (i.e. left, central or right side of spine). For the left and right sides, each area consisted of 6 stimulation sites. The central area consisted of 3 sites (see Appendices 12 and 14). A correct response occurred when a participant named any of the sites within the same region as the stimulated site.

The distribution of both groups was skewed to the left indicating excellent localisation ability, at least according to the area of testing (Table 6.36 and Figure 6.36). Due to the skewed distribution, the data was transformed using a log10 transformation and the resulting data was consistent with a normal distribution. An independent-samples t-test was used to test the statistical significance of the difference between groups. As the result was the same as for the non-transformed data, the results of the non-transformed data analysis is presented here for simplicity (Table 6.37).

On average, the mean difference in localisation accuracy by area between case and control participants was small (mean number correct = 26.96 or 89.9%; and 28.55 or 95.2% respectively). This difference was statistically significant (difference in means = -1.59 or 5.3%; 95% CI -2.47, -0.71; t = -3.59; df = 65.06; p = 0.001; *d* = -0.95) suggesting that control participants were slightly more accurate on average than case participants.

A point-biserial correlation was run to determine the relationship between regional localisation ability and group type. Group type was significantly related to the localisation accuracy (r_{pb} = 0.300; 95% BCa CI 0.157, 0.434; p<0.001) although it shared only 9% of the variability in regional accuracy (r_{pb}^2=0.090) (Table 6.38).

Table 6.36 Localisation descriptive statistics - Case v Control side (max=30)

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)	missing %
case (n=57)	26.96	3.21	0.43	26.1, 27.8	28.00	25.5, 29	17	30	1	1.7
control (n=197)	28.55	1.68	0.12	28.3, 28.8	29.00	28, 30	20	30	0	0.0

Figure 6.36 Localisation histograms, boxplots & means (95% CI) - Case v Control (side)

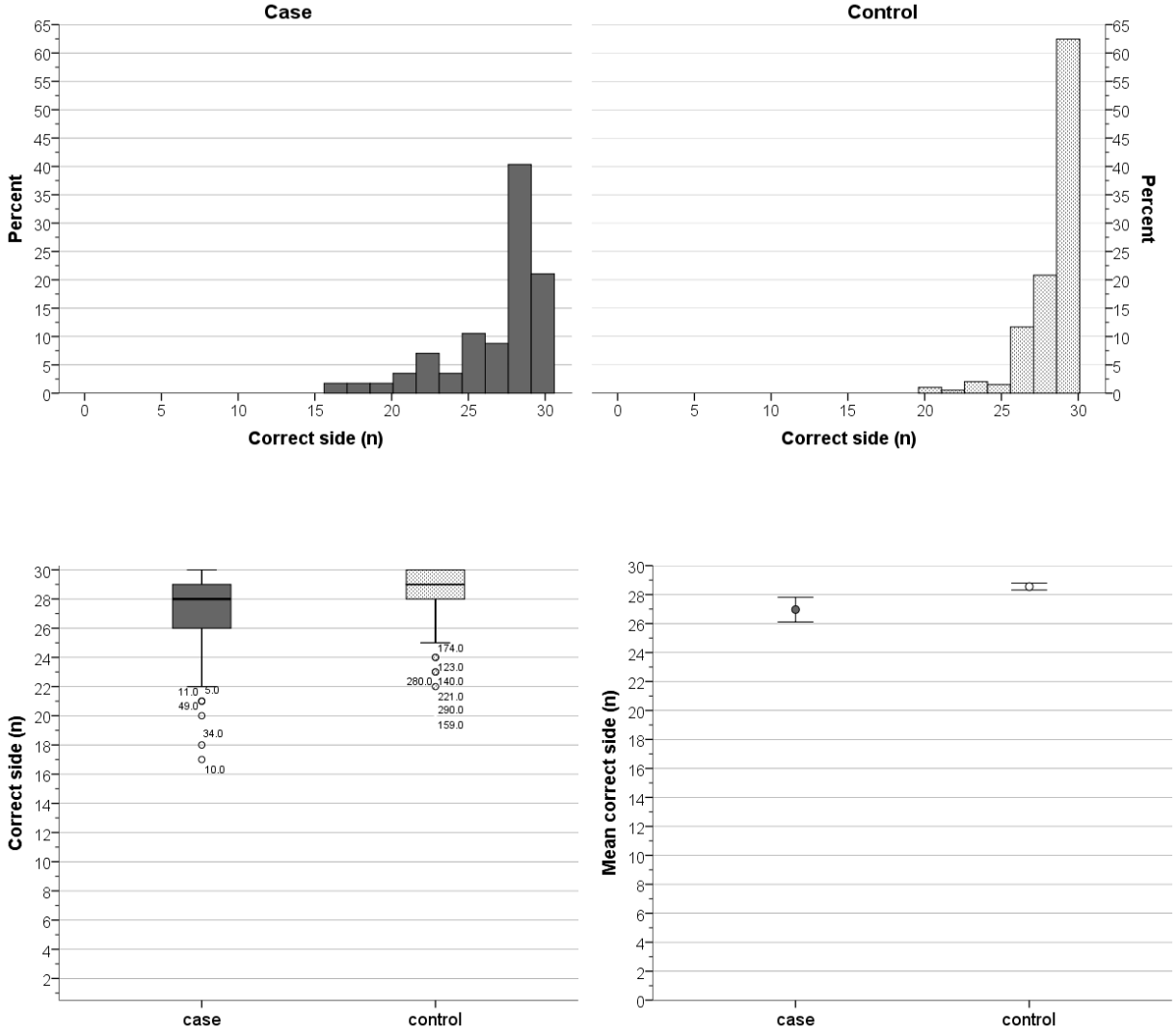


Table 6.37 Localisation - results of statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	side	-1.59	-2.47, -0.71	-3.59	65.06	0.001*	-0.95

* = statistically significant

Table 6.38 Correlation between localisation accuracy and group (case/control)

analysis	test	location	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	side (left, centre, right)	0.300	0.157, 0.434	0.090	<0.001*

* statistically significant

6.10 Laterality discrimination

6.10.1 Accuracy (hands)

6.10.1.1 Left v Right side

Two trials of 50 images each were undertaken. Participants had to choose whether the presented image was of a left or right hand (25 each per trial, 50 in total for each side). Accuracy was calculated as the percentage of correct responses for each side.

Descriptive statistics and distributions are provided in Table 6.39 and illustrated in

Figure 6.37 to Figure 6.38. Statistical analysis of the difference between left and right judgement accuracy within each group was conducted with a paired-samples t-test (Table 6.40).

For cases, on average, there was little difference in ability to discriminate between left and right hands (mean accuracy = 78.7% and 81.3% respectively). However, this difference was statistically significant (mean difference = -2.62%; 95% CI -4.81, -0.42; t = -2.39; DF = 57; p = 0.02; *d* = -0.22).

Similarly for controls, on average there was little difference between tests performed on the left and right sides (mean accuracy = 77.4% and 78.2% respectively) and this difference was not statistically significant (mean difference = -0.71%; 95% CI -1.82, 0.40; t = -1.26; DF = 196; p = 0.21; *d* = -0.05).

Table 6.39 Laterality discrimination descriptive statistics - Accuracy Left v Right hands

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	L	78.69	12.86	1.69	75.3, 82.1	79.0	72, 86	46.0	100	0
	R	81.31	11.46	1.50	78.3, 84.3	82.0	73.5, 90	48.0	100	0
control (n=197)	L	77.44	14.76	1.05	75.4, 79.5	80.0	66, 90	38.0	100	0
	R	78.15	14.85	1.06	76.1, 80.2	82.0	68, 90	30.0	100	0

*L = left; R = Right

Figure 6.37 Laterality discrimination histograms & boxplots - Accuracy Left v Right hands

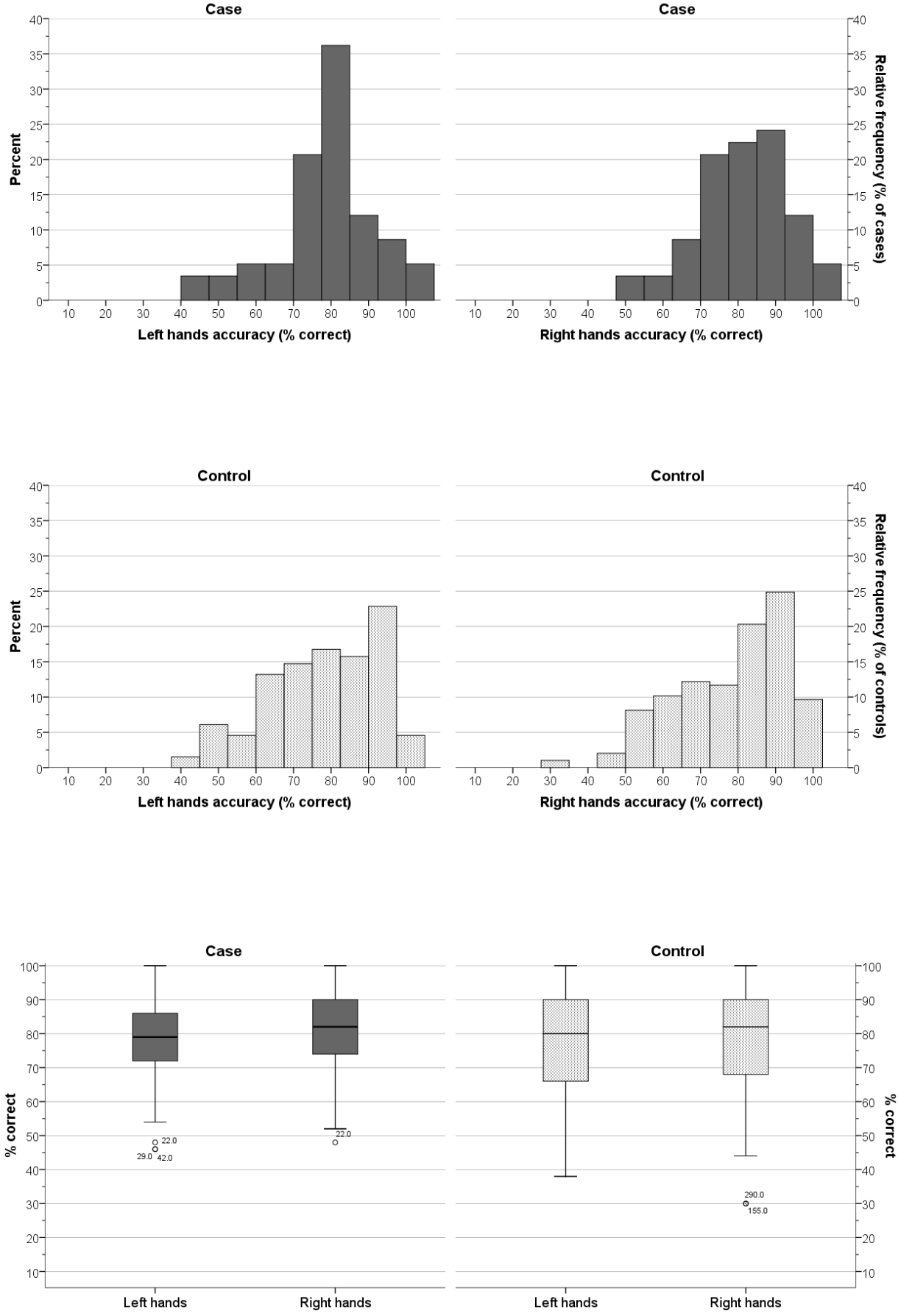


Figure 6.38 Laterality discrimination means (95% CI) - Accuracy Left v Right hands

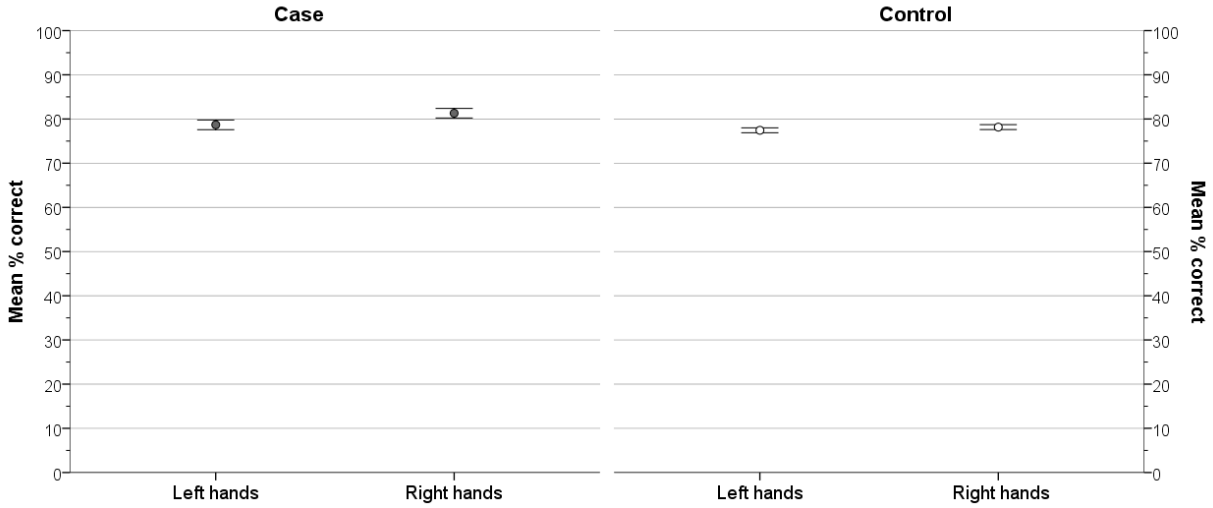


Table 6.40 Laterality discrimination Accuracy Left v Right Hands - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Left v Right	paired t-test	case	-2.62	-4.81, -0.42	-2.39	57	0.02*	-0.22
		control	-0.71	-1.82, 0.40	-1.26	196	0.21	-0.05

* = statistically significant

6.10.1.2 Affected v Unaffected side

The affected side refers to images of the hand that correspond to the direction of the curve in case participants. For example, if the curve was convex to the right, then images of the right hand were categorised as the affected side. For control participants, the affected and unaffected side were determined by their matching case.

Descriptive statistics for Affected and Unaffected side are described in Table 6.41 and illustrated in Figure 6.39 and Figure 6.40. Statistical analysis of the difference between Affected and Unaffected localisation accuracy within each group was conducted with a paired-samples t-test (Table 6.42).

For cases, on average, there was little difference in laterality discrimination ability between images that corresponded to the affected or unaffected side (mean accuracy = 80.0% and 79.6% respectively) and this difference was not statistically significant (mean difference = 0.42%; 95% CI -1.91, 2.75; t = 0.36; DF = 56; p = 0.72; *d* = 0.03).

Similarly for controls, on average there was little difference between the affected or unaffected side (mean accuracy = 77.5% and 77.8% respectively) and this was also not statistically significant (mean difference = -0.33%; 95% CI -1.46, 0.80; t = -0.58; DF = 193; p = 0.56; *d* = -0.02).

Table 6.41 Laterality discrimination descriptive statistics - Accuracy Affected v Unaffected hands

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
case (n=57)	A	80.0	12.1	1.60	76.8, 83.2	82	72, 89	46	100	1 (1.7)
	U	79.6	12.5	1.66	76.3, 82.9	82	75, 86	46	100	1 (1.7)
control (n=194)	A	77.5	15.3	1.09	75.4, 79.7	80	67.5, 90	30	100	3 (1.5)
	U	77.8	14.5	1.04	75.8, 79.9	80	68, 90	38	100	3 (1.5)

Figure 6.39 Laterality discrimination histograms & boxplots - Accuracy Affected v Unaffected hands

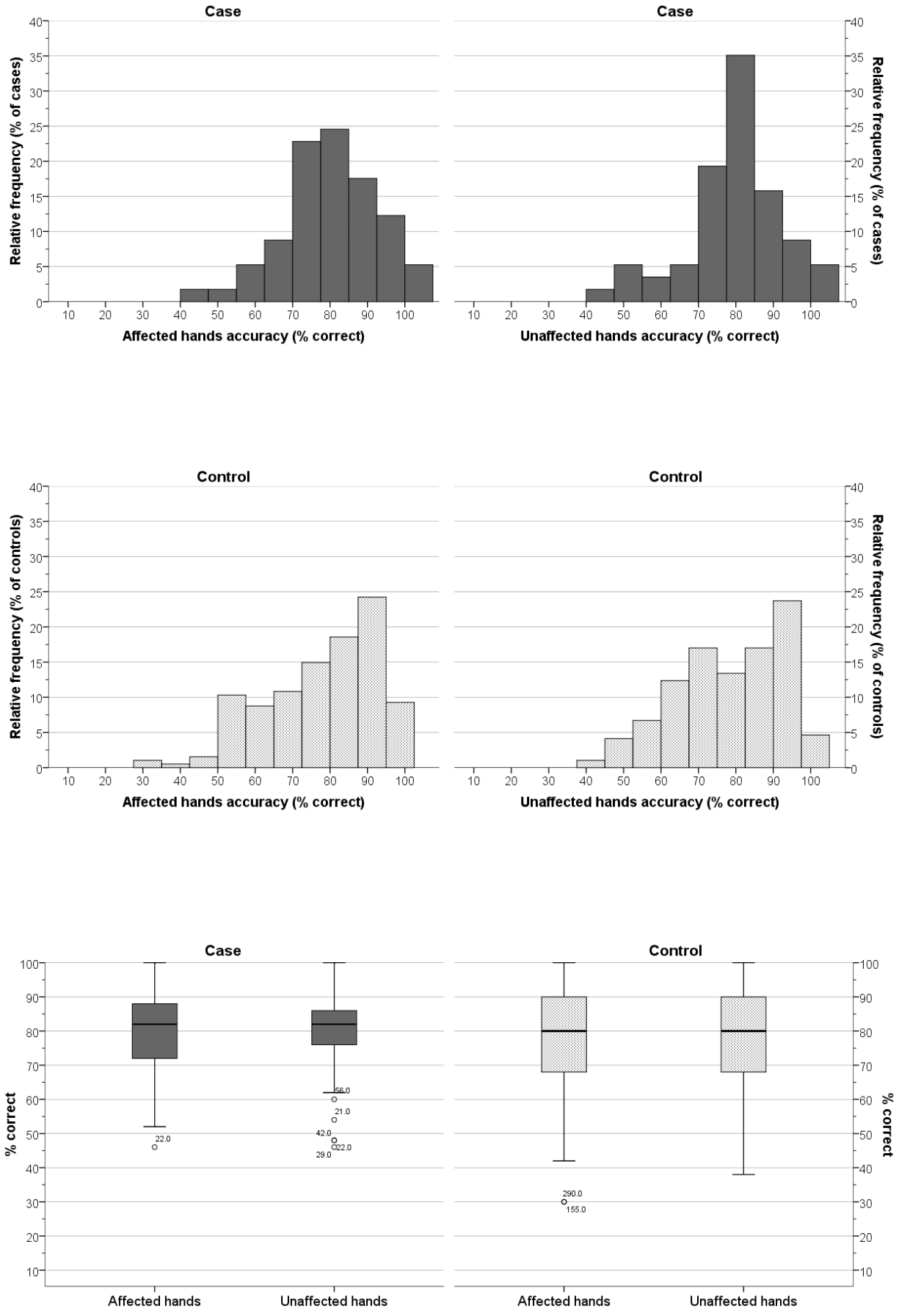


Figure 6.40 Laterality discrimination means (95% CI) - Accuracy Affected v Unaffected hands

Table 6.42 Laterality discrimination Accuracy Affected v Unaffected Hands - statistical results

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Affected v unaffected	paired t-test	case	0.42	-1.91, 2.75	0.36	56	0.72	0.03
		control	-0.33	-1.46, 0.80	-0.58	193	0.56	-0.02

6.10.1.3 Case v Control

Data was combined to form one Case and one Control variable allowing for a direct comparison between the two groups. The distribution of accuracy scores for cases was consistent with a normal distribution (Table 6.43 and Figure 6.41). For controls, data was skewed to the left suggesting a non-normal distribution. Data for both groups was transformed using a square root transformation which resulted in a normal distribution for cases and controls. An independent-samples t-test was used to test the statistical significance of the difference between groups. The results of this were the same as for the analysis of non-transformed data, therefore the results of the non-transformed analysis is presented here (Table 6.44).

On average, the mean difference in left/right judgement ability between case and control participants was small (mean accuracy = 80.0% and 77.8% respectively). This difference was not statistically significant (difference in means = 2.2%; 95% CI -1.39, 5.80; t = 1.21; df = 114.1; p = 0.23; *d* = 0.15) suggesting that case and control participants were equivalent in their ability to determine whether the viewed images were of the right or left hand.

A point-biserial correlation was run to determine the relationship between left/right judgement accuracy of the hands and group type. Group type was not significantly related to accuracy (r_{pb} = 0.068; 95% BCa CI 0.048, 0.181; p=0.282) and shared only 0.5% of the variability in accuracy (r_{pb}^2=0.005) (Table 6.45).

Table 6.43 Laterality discrimination descriptive statistics - Accuracy Case v Control hands

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	80.0	11.4	1.50	77.0, 83.0	80	73.8, 86.5	47	100	0
control (n=197)	77.8	14.3	1.02	75.8, 79.8	81	66.5, 89.5	38	100	0

Figure 6.41 Laterality discrimination histograms, boxplots & means (95% CI) - Accuracy Case v Control hands

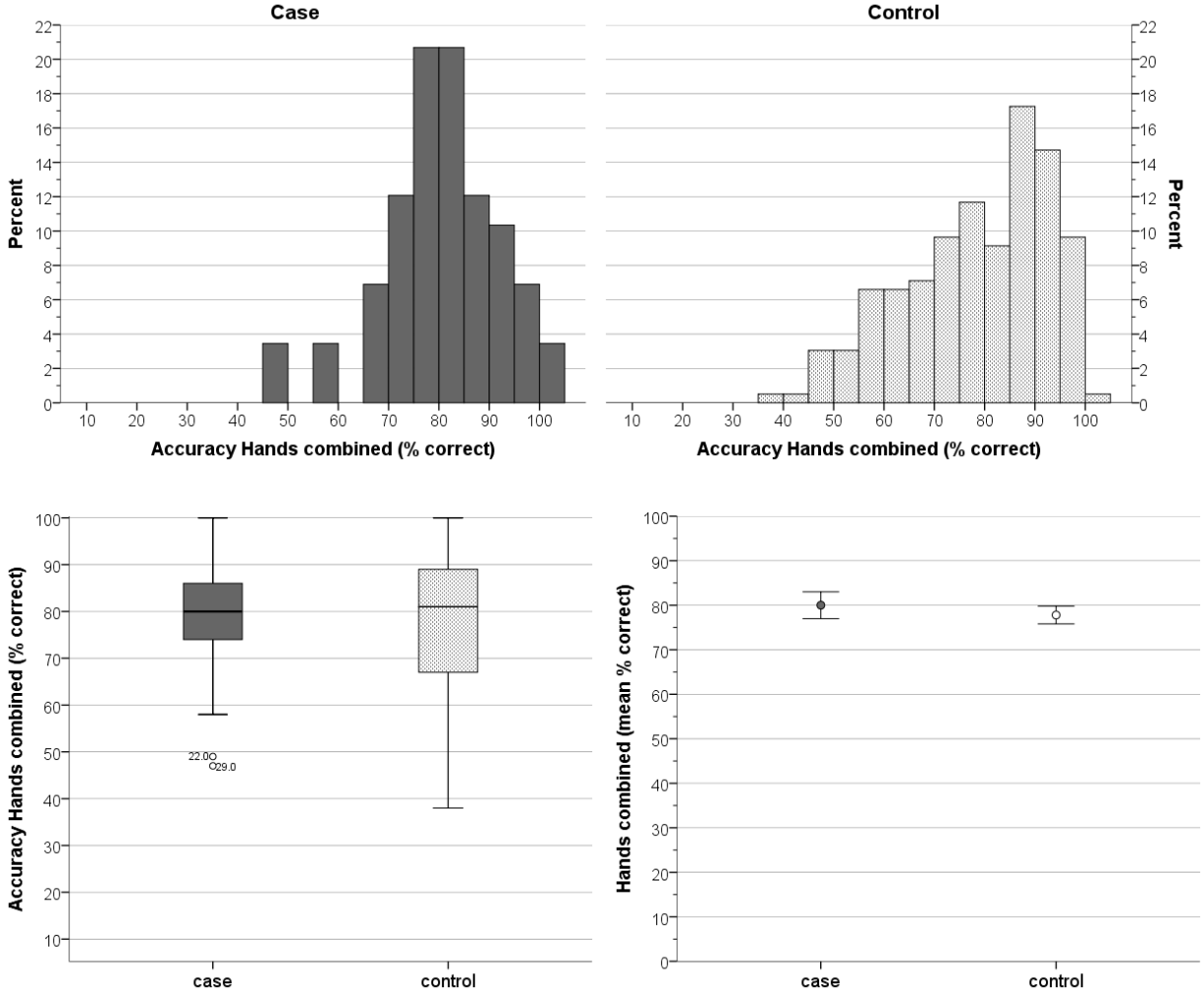


Table 6.44 Laterality discrimination Hand accuracy case v control- statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	side	2.20	-1.39, 5.80	1.21	114.11	0.23	0.15

Table 6.45 Correlation between group type and Hand accuracy - Laterality discrimination

analysis	test	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	0.068	-0.048, 0.181	0.005	0.282

6.10.2 Accuracy (back)

6.10.2.1 Left v Right

Participants were required to judge whether the images depicted movement of the trunk to the left or the right. Descriptive statistics and distributions are provided in Table 6.46 and Figure 6.42 to Figure 6.43. Statistical analysis of the difference between left and right judgement accuracy within each group was conducted with a paired-samples t-test (Table 6.47).

For cases, on average, there was little difference in ability to discriminate between images depicting movement to the left and right (mean accuracy = 84.7% and 86.7% respectively). However, this difference was statistically significant (mean difference = -2.0%; 95% CI -3.78, -0.22; t = -2.25; DF = 57; p = 0.03; *d* = -0.18).

Similarly for controls, on average there was little difference between images showing left and right movement (mean accuracy = 84.6% and 84.7% respectively) and this difference was not statistically significant (mean difference = -0.13%; 95% CI -1.09, 0.82; t = -2.72; DF = 196; p = 0.79; *d* = -0.01).

Table 6.46 Laterality discrimination descriptive statistics - Accuracy Left v Right back (% correct)

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	L	84.7	12.8	1.68	81.4, 88.1	88	79.5, 92	34	100	0
	R	86.7	10.0	1.31	84.1, 89.4	90	80, 94	60	100	0
control (n=197)	L	84.6	10.6	0.75	83.1, 86.1	86	78, 92	36	100	0
	R	84.7	10.0	0.71	83.3, 86.1	86	78, 93	54	100	0

* L - left; R = right

Figure 6.42 Laterality discrimination histograms & boxplots - Accuracy Left v Right back

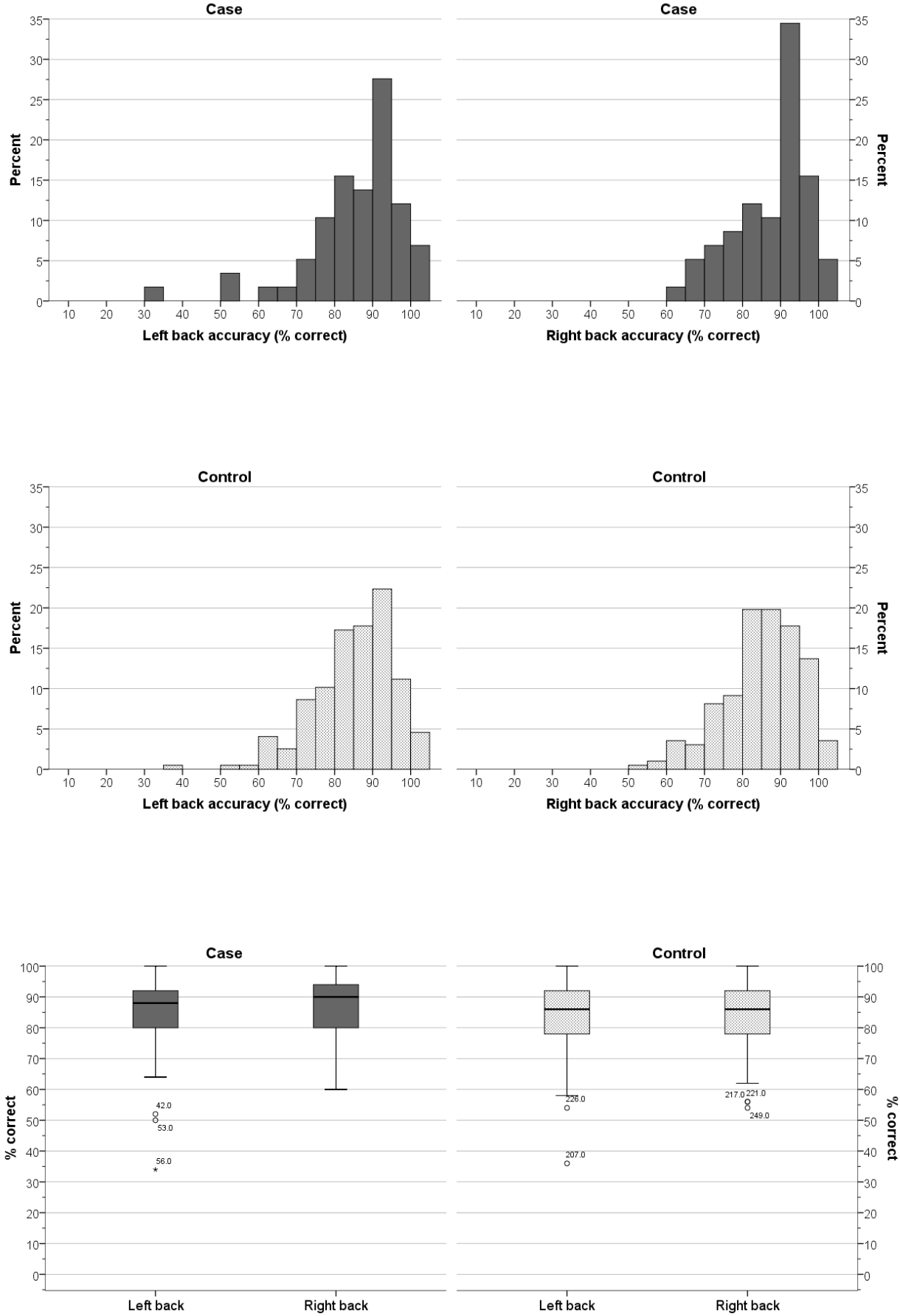


Figure 6.43 Laterality discrimination means (95% CI) - Accuracy Left v Right

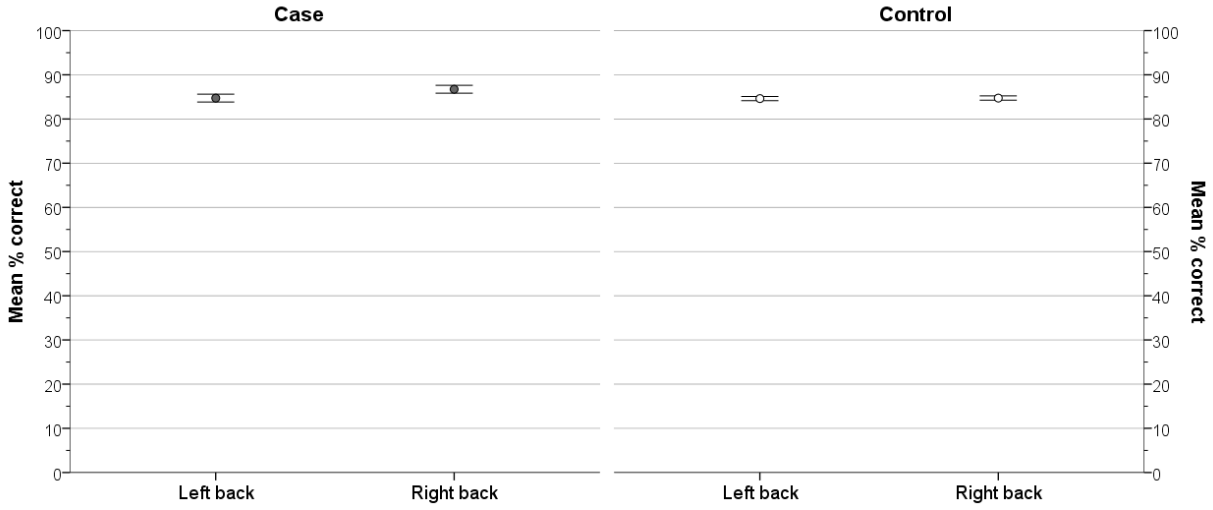


Table 6.47 Laterality discrimination Back accuracy Left v Right - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Left v Right	paired t-test	case	-2.00	-3.78, -0.22	-2.25	57	0.03*	-0.18
		control	-0.13	-1.09, 0.82	-2.72	196	0.79	-0.01

* = statistically significant

6.10.2.2 Affected v Unaffected

The affected side refers to images of the trunk movement that correspond to the direction of the curve in case participants. For example, if the curve was convex to the right, then images of movement to the right were categorised as the affected side. For control participants, the affected and unaffected side were determined by their matching case.

Descriptive statistics for Affected and Unaffected side are described in Table 6.48 and Figure 6.44 and Figure 6.45. Statistical analysis of the difference between Affected and Unaffected accuracy within each group was conducted with a paired-samples t-test (Table 6.49).

For cases, on average, there was little difference in ability to discriminate between images depicting movement to the affected or unaffected side (mean accuracy = 86.0% and 85.3% respectively) and this difference was not statistically significant (mean difference = 0.74%; 95% CI -1.13, 2.60; t = 0.79; DF = 56; p = 0.43; *d* = 0.06).

Similarly for controls, on average there was little difference between the affected or unaffected side (mean accuracy = 84.5% and 84.6% respectively) and this was also not statistically significant (mean difference = -0.09%; 95% CI -1.06, 0.87; t = -0.19; DF = 193; p = 0.85; *d* = -0.01).

Table 6.48 Laterality discrimination descriptive statistics - Accuracy Affected v Unaffected back

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
case (n=57)	A	86.0	10.1	1.34	83.4, 88.7	88	78, 94	60	100	1 (1.7)
	U	85.3	12.9	1.71	81.9, 88.7	90	80, 92	34	100	1 (1.7)
control (n=194)	A	84.5	10.2	0.73	83.1, 86	86	78, 92	54	100	3 (1.5)
	U	84.6	10.4	0.75	83.1, 86.1	86	78, 92	36	100	3 (1.5)

*A = affected side; U = unaffected side

Figure 6.44 Laterality discrimination histograms & boxplots - Accuracy Affected v Unaffected back

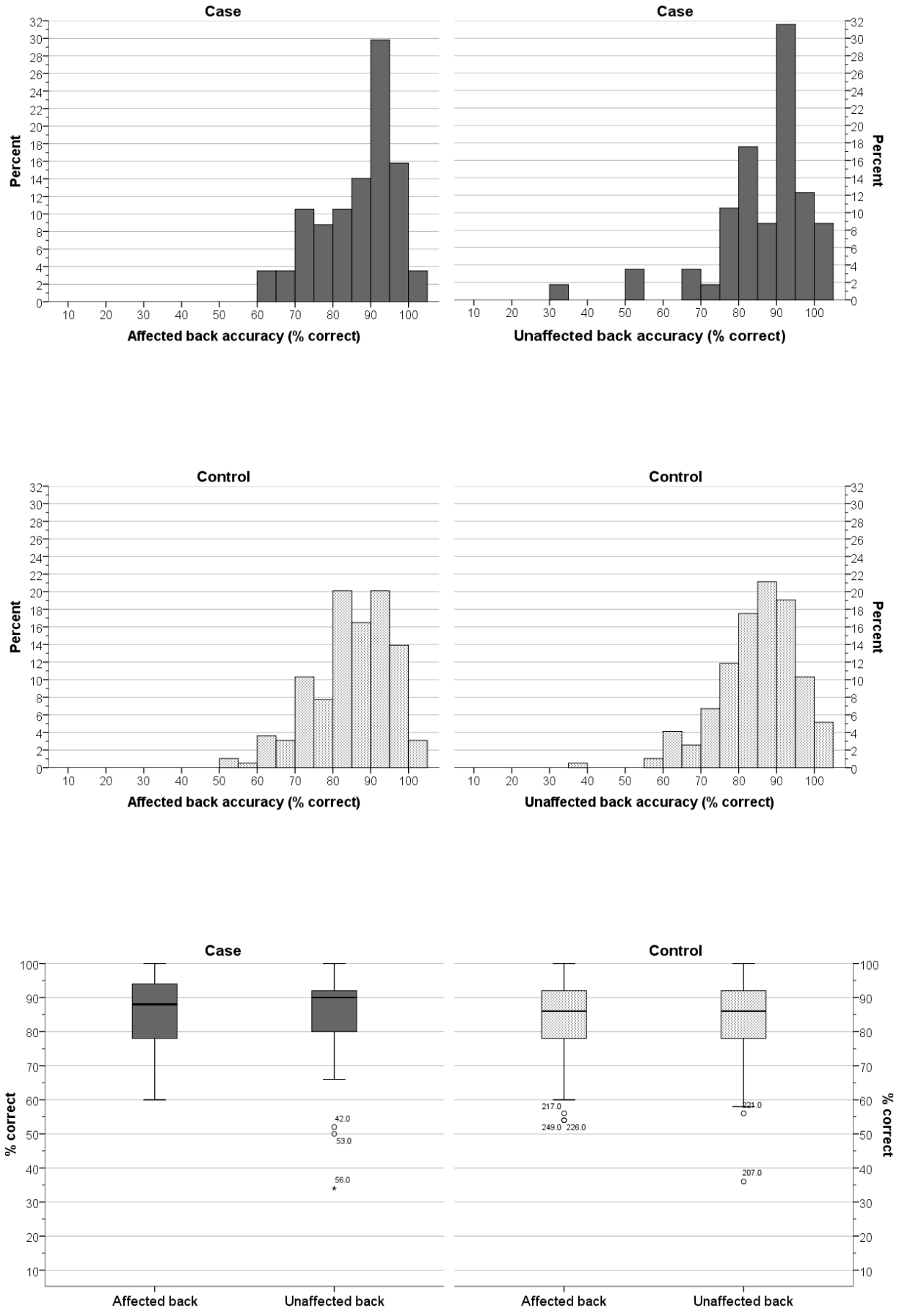


Figure 6.45 Laterality discrimination means (95% CI) - Accuracy Affected v Unaffected back

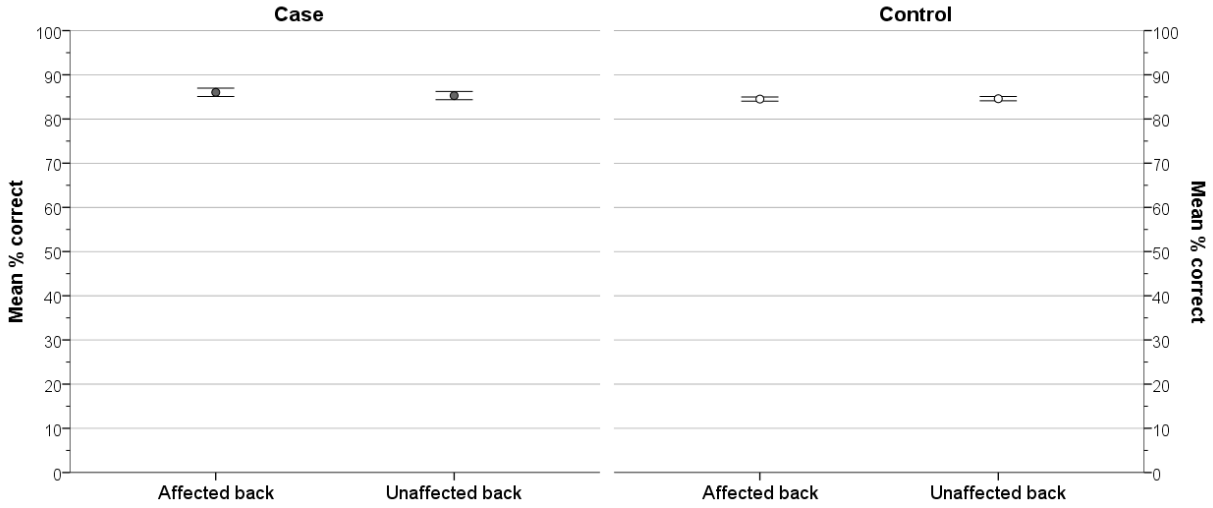


Table 6.49 Laterality discrimination Back accuracy Affected v Unaffected - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Affected v unaffected	paired t-test	case	0.74	-1.13, 2.60	0.79	56	0.43	0.06
		control	-0.09	-1.06, 0.87	-0.19	193	0.85	-0.01

* = statistically significant

6.10.2.3 Case v Control

Data was combined to form one Case and one Control variable allowing for a direct comparison between the two groups. The distribution of both groups was consistent with a normal distribution (Table 6.50 and Figure 6.46). An independent-samples t-test was used to test the statistical significance of the difference between groups (Table 6.51).

On average, the mean difference in ability to judge the direction of trunk movement between case and control participants was small (mean accuracy = 85.7% and 84.7% respectively). This difference was not statistically significant (difference in means = 1.05%; 95% CI -1.89, 3.99; t = 0.7; df = 253; p = 0.48; *d* = 0.11) suggesting that case and control participants were equivalent in their ability to determine direction of trunk movement.

A point-biserial correlation was run to determine the relationship between left/right judgement accuracy of the back and group type. Group type was not significantly related to accuracy (r_{pb} = 0.044; 95% BCa CI -0.087, 0.169; p=0.483) and shared only 0.2% of the variability in accuracy (r_{pb}^2=0.002) (Table 6.52).

Table 6.50 Laterality discrimination descriptive statistics - Accuracy Case v Control back

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	85.7	10.96	1.44	82.8, 88.6	89.0	78.8, 93.3	47.0	99.0	0
control (n=197)	84.7	9.69	0.69	83.3, 86.0	86.0	79.0, 92.0	50.0	100	0

Figure 6.46 Laterality discrimination histograms, boxplots & means (95% CI) - Accuracy Case v Control back

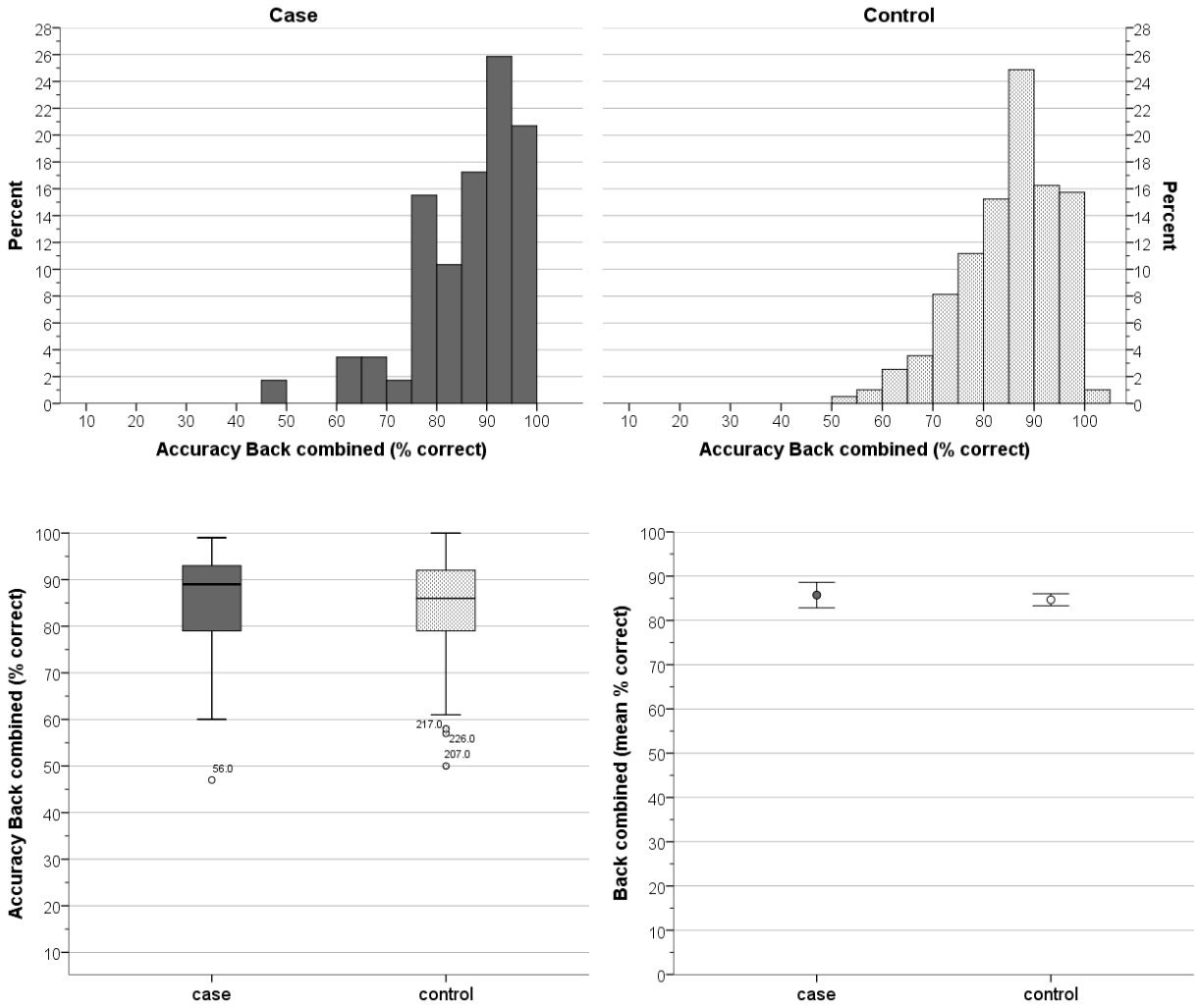


Table 6.51 Laterality discrimination Accuracy back - results of statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	side	1.05	-1.89, 3.99	0.70	253	0.48	0.11

* = statistically significant

Table 6.52 Correlation of group and Back accuracy - Laterality discrimination

analysis	test	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	0.044	-0.087, 0.169	0.002	0.483

* statistically significant

6.10.3 Reaction time (hands)

The time to make a judgement of which hand was displayed in the image was recorded. The following analyses only evaluate reaction times for correct responses.

6.10.3.1 Left v Right

Descriptive statistics and distributions are provided in Table 6.53 and Figure 6.47 to Figure 6.48. Statistical analysis of the difference in reaction times between correct responses of the left and right hands within each group was conducted with a paired-samples t-test (Table 6.54).

For cases, on average, there was little difference in reaction between images of the left and right hand (mean reaction time = 3.16 seconds and 3.17 seconds respectively) and this difference was not statistically significant (mean difference = -0.004 sec; 95% CI -0.15, 0.14; t = -0.05; DF = 57; p = 0.96; *d* = -0.003).

Similarly for controls, on average there was little difference between tests performed on the left and right sides (mean reaction time = 2.82 seconds and 2.79 seconds respectively) and this difference was also not statistically significant (mean difference = 0.032 sec; 95% CI -0.03, 0.09; t = 1.06; DF = 196; p = 0.29; *d* = 0.03).

Table 6.53 Laterality discrimination descriptive statistics - Accuracy Left v Right hands (sec)

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	L	3.16	1.27	0.17	2.83, 3.50	3.13	2.44, 3.50	1.41	8.60	0
	R	3.17	1.31	0.17	2.51, 3.52	3.06	2.51, 3.52	1.33	9.61	0
control (n=197)	L	2.82	1.02	0.73	2.68, 2.97	2.66	2.06, 3.38	1.18	6.43	0
	R	2.79	1.06	0.75	2.64, 2.94	2.70	2.02, 3.33	1.00	7.37	0

* L = left; R = right

Figure 6.47 Laterality discrimination histograms & boxplots - Reaction times Left v Right hands

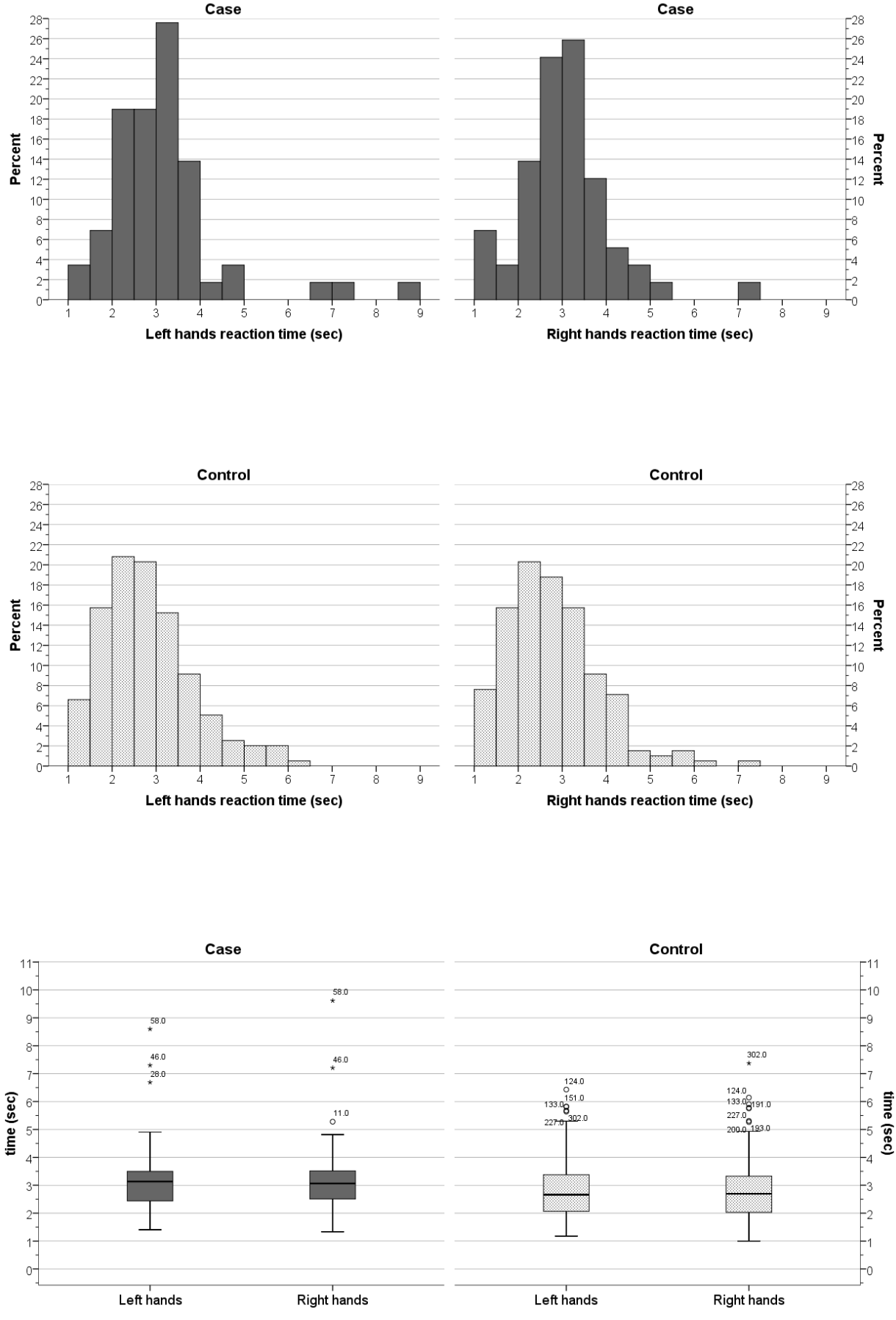


Figure 6.48 Laterality discrimination means (95% CI) - Reaction times Left v Right hands

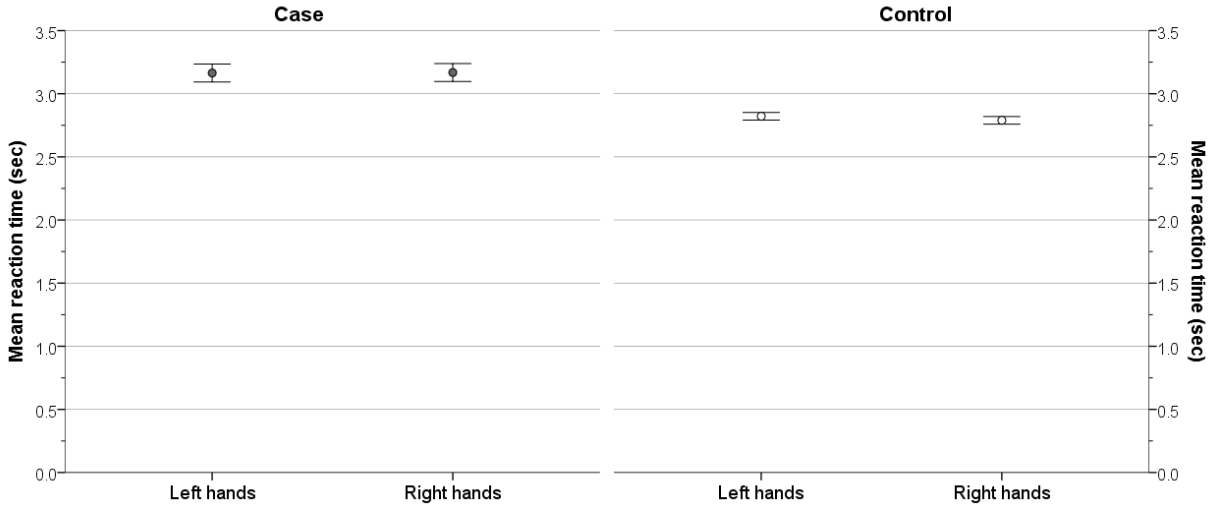


Table 6.54 Laterality discrimination Reaction time hands - left v right statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Left v Right (sec)	paired t-test	case	-0.004	-0.146, 0.138	-0.05	57	0.96	-0.003
		control	0.032	-0.028, 0.092	1.06	196	0.29	0.03

6.10.3.2 Affected v Unaffected

Descriptive statistics for Affected and Unaffected side are described in Table 6.55 and Figure 6.49 and Figure 6.50. Statistical analysis of the difference in reaction times between hand images that corresponded to the Affected and Unaffected side within each group was conducted with a paired-samples t-test (Table 6.56).

For cases, on average, there was little difference in reaction times between the affected or unaffected side (mean reaction time = 3.14 seconds and 3.11 seconds respectively) and this difference was not statistically significant (mean difference = 0.04 sec; 95% CI -0.09, 0.16; t = 0.57; DF = 56; p = 0.57; *d* = 0.03).

Similarly for controls, on average there was little difference between the affected or unaffected side (mean reaction time = 2.80 seconds and 2.82 seconds respectively) and this was also not statistically significant (mean difference = -0.019 sec; 95% CI -0.08, 0.04; t = --0.06; DF = 193; p = 0.55; *d* = -0.02).

Table 6.55 Laterality discrimination descriptive statistics - Reaction time Affected v Unaffected hands (sec)

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=57)	A	3.14	1.30	0.17	2.80, 3.48	3.05	2.48, 3.51	1.33	9.61	1 (1.7)
	U	3.11	1.21	0.16	2.79, 3.43	3.08	2.43, 3.47	1.41	8.60	1 (1.7)
control (n=194)	A	2.80	1.07	0.08	2.65, 2.96	2.63	2.02, 3.39	1.16	7.37	3 (1.5)
	U	2.82	1.02	0.07	2.68, 2.97	2.70	2.08, 3.35	1.00	6.14	3 (1.5)

Figure 6.49 Laterality discrimination histograms & boxplots - Reaction time Affected v Unaffected hands

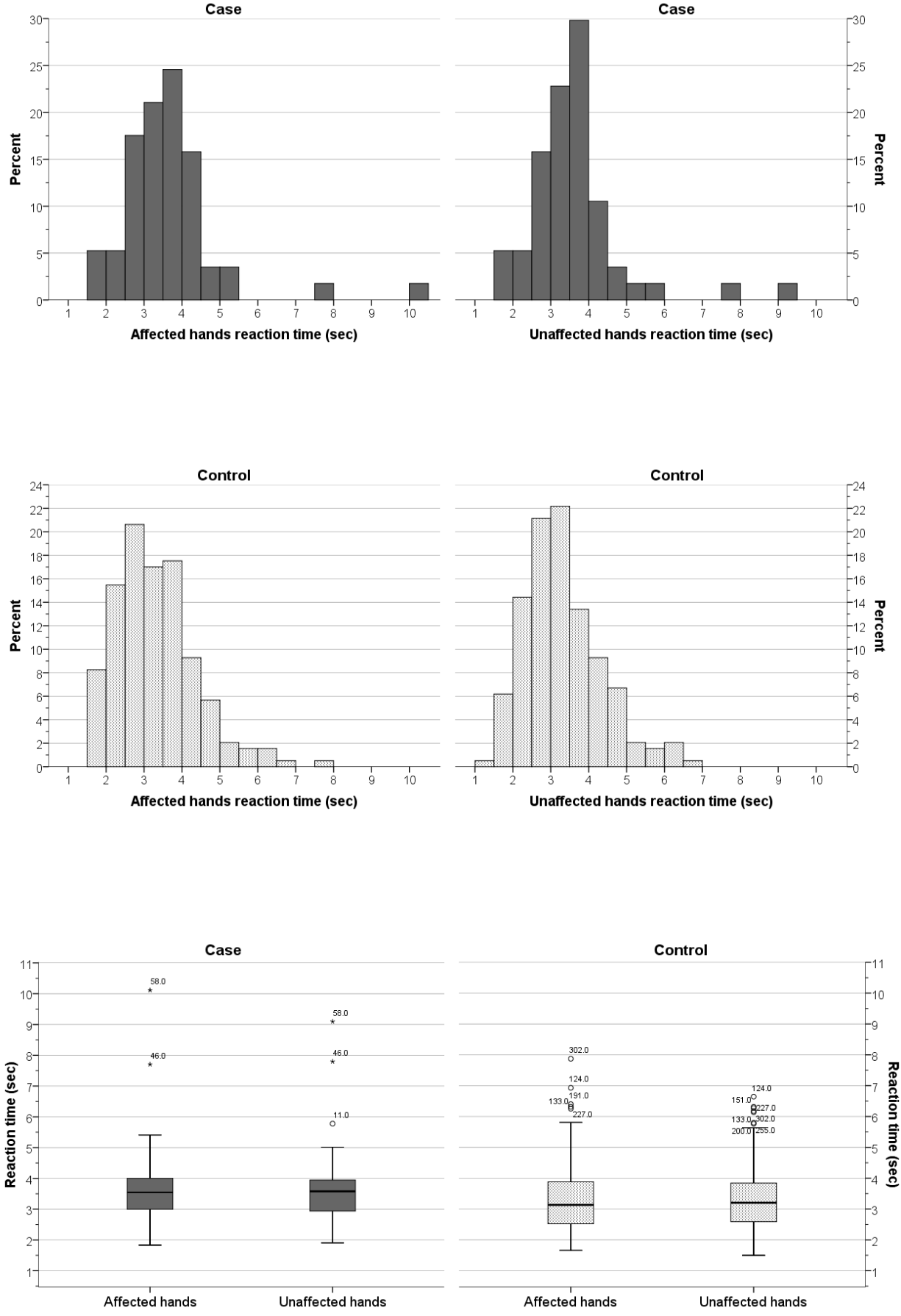


Figure 6.50 Laterality discrimination means (95% CI) - Reaction time Affected v Unaffected hands

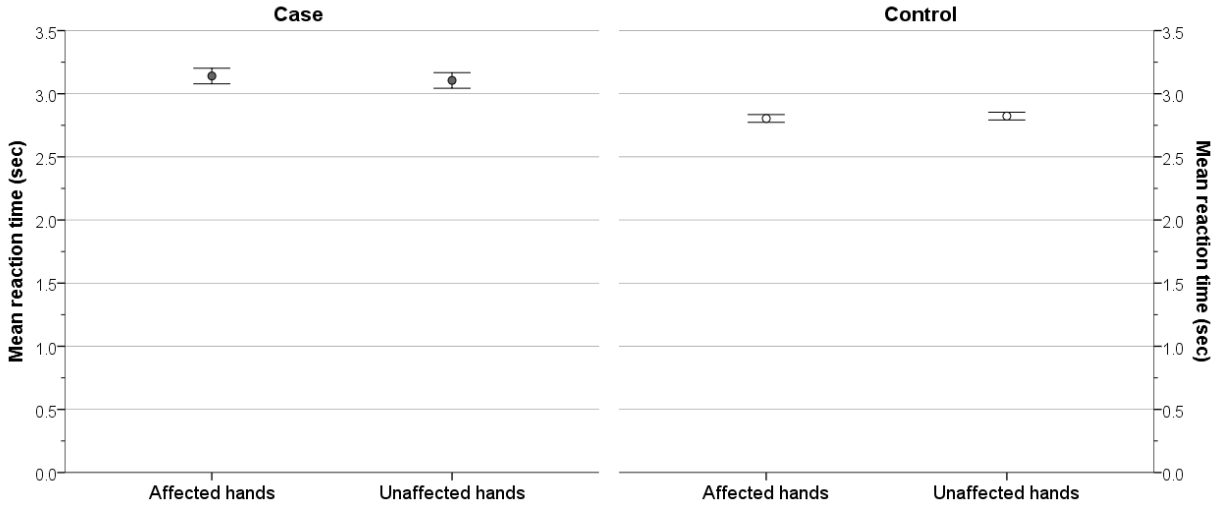


Table 6.56 Laterality discrimination Reaction time Hands - Affected v Unaffected statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Affected v unaffected (sec)	paired t-test	case	0.035	-0.088, 0.159	0.57	56	0.57	0.03
		control	-0.018	-0.079, 0.042	-0.60	193	0.550	-0.02

6.10.3.3 Case v Control

Data was combined to form one Case and one Control variable allowing for a direct comparison between the two groups (Table 6.57 and Figure 6.51). The distribution of both groups was skewed to the right, therefore a log10 transformation was applied resulting in transformed data consistent with a normal distribution. An independent-samples t-test was used to test the statistical significance of the difference between groups using the transformed data. The results of this analysis was the same as for the non-transformed data, therefore the results of the non-transformed analysis are presented here (Table 6.58).

On average, the mean difference in reaction time for left/right judgements of the hand between case and control participants was small (mean reaction time = 3.17 seconds and 2.81 seconds respectively). However, this difference was statistically significant (difference in means = 0.36 sec; 95% CI 0.04, 0.68; t = 2.24; df = 253; p = 0.03; *d* = 0.35) suggesting that case participants were slower in making left/right judgements of the hand than controls.

A point-biserial correlation was run to determine the relationship between left/right judgement reaction time and group type. Group type was significantly related to reaction time (r_{pb} = 0.140; 95% BCa CI 0.017, 0.261; p=0.026) although it shared only 2% of the variability in reaction time for the hands (r_{pb}^2=0.020) (Table 6.59).

Table 6.57 Laterality discrimination descriptive statistics - Reaction time Case v Control hands

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	3.17	1.26	0.17	2.83, 3.50	3.07	2.52, 3.52	1.37	9.11	0
control (n=197)	2.81	1.02	0.07	2.66, 2.95	2.73	2.06, 3.39	1.09	6.53	0

Figure 6.51 Laterality discrimination histograms, boxplots & means (95% CI) - Reaction time Case v Control hands

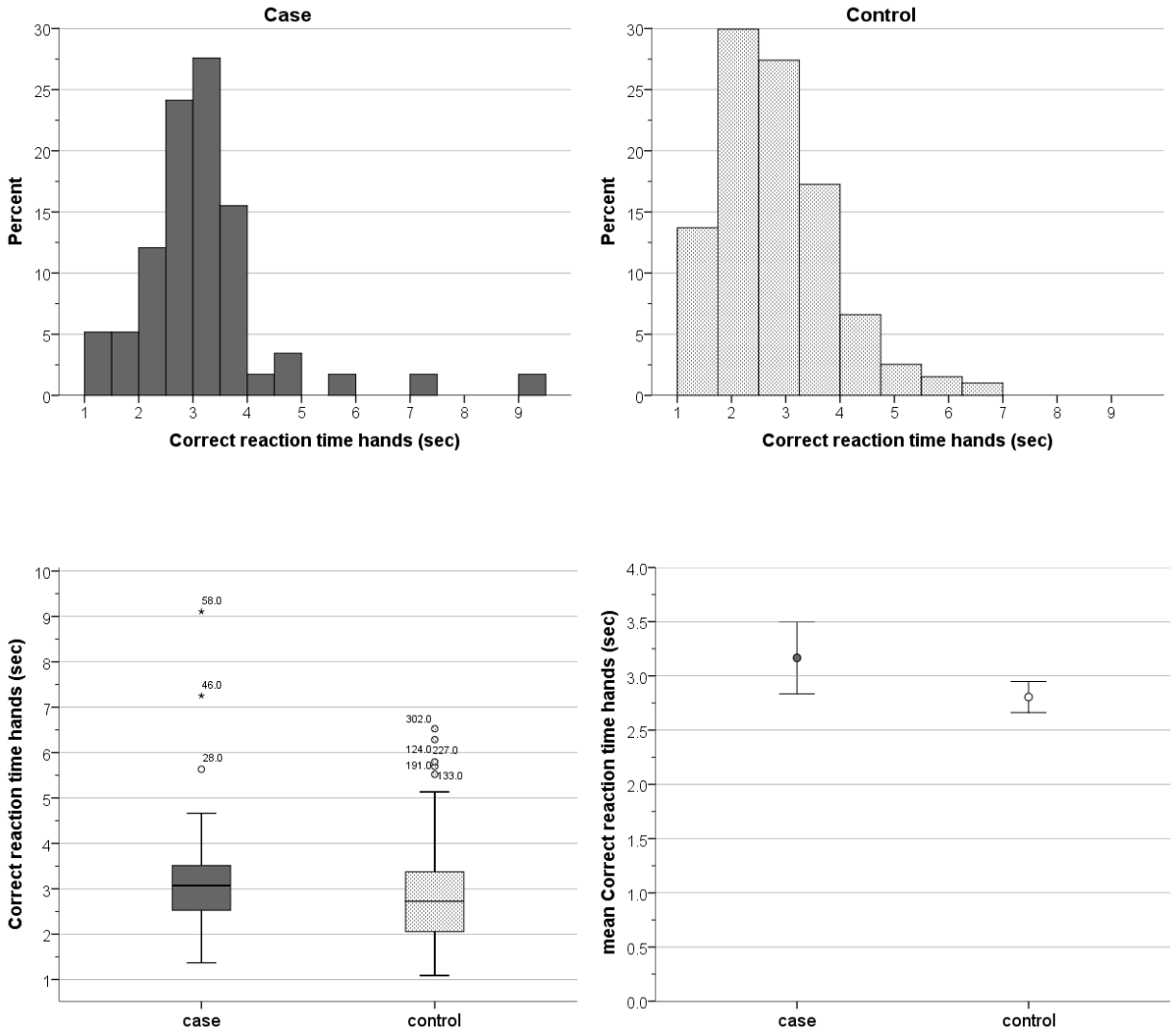


Table 6.58 Laterality discrimination Reaction time hands - case v control statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	side	0.361	0.044, 0.678	2.24	253	0.03*	0.35

* = statistically significant

Table 6.59 Correlation between group type and Reaction time Hands - Laterality discrimination

analysis	test	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	0.140	0.017, 0.261	0.020	0.026

* statistically significant

6.10.3.4 Correct v Incorrect

A within-group analysis was undertaken to evaluate whether reaction times for correct responses were different to those of incorrect responses. For cases, the average incorrect response reaction time for one participant was more than three times longer than the next highest value (23.45 seconds and 7.20 seconds respectively). Therefore, the reaction time for incorrect responses for this participant was not included in the analysis.

Descriptive statistics for correct and incorrect reaction times for left/right hand judgements are described in Table 6.60 and Figure 6.52 and Figure 6.53. Statistical analysis of the difference in reaction times between correct and incorrect judgements within each group was conducted with a paired-samples t-test (Table 6.61).

For cases, on average, there was little difference in reaction times between correct and incorrect judgements (mean reaction time = 3.17 seconds and 3.65 seconds respectively) although this difference was statistically significant (mean difference = -0.47 sec; 95% CI --0.29, -0.65; t = -5.26; DF = 55; p<0.001; *d* = -0.33).

For controls, on average there was a smaller difference between correct and incorrect reaction times (mean reaction time = 2.81 seconds and 3.18 seconds respectively) and this was also statistically significant (mean difference = -0.383 sec; 95% CI -0.27, -0.50; t = --6.45; DF = 195; p<0.001; *d* = -0.30).

Table 6.60 Laterality discrimination descriptive statistics - Reaction times Correct v Incorrect hands (sec)

	trial*	n	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case	C	58	3.17	1.26	0.17	2.83, 3.50	3.07	2.52, 3.52	1.37	9.11	0
	I	56	3.65	1.60	0.21	3.22, 4.08	3.43	2.87, 4.07	1.29	12.11	2
control	C	197	2.81	1.02	0.07	2.66, 2.95	2.73	2.06, 3.39	1.09	6.53	0
	I	196	3.18	1.47	0.10	2.97, 3.39	2.86	2.07, 4.07	1.05	8.45	1

* C = correct; I = incorrect

Figure 6.52 Laterality discrimination histograms & boxplots - Reaction times Correct v Incorrect hands

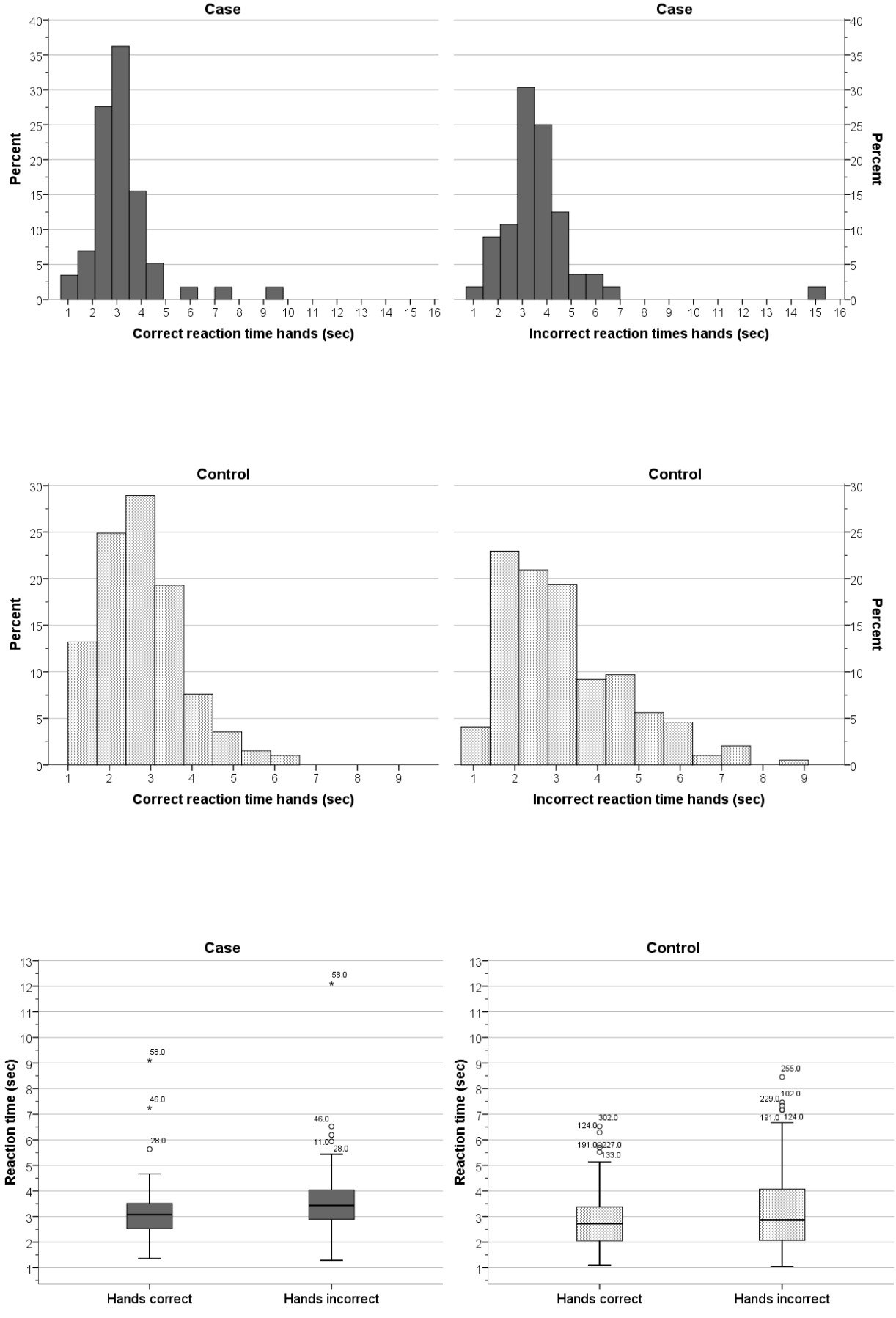


Figure 6.53 Laterality discrimination means (95% CI) - Reaction times Correct v Incorrect hands

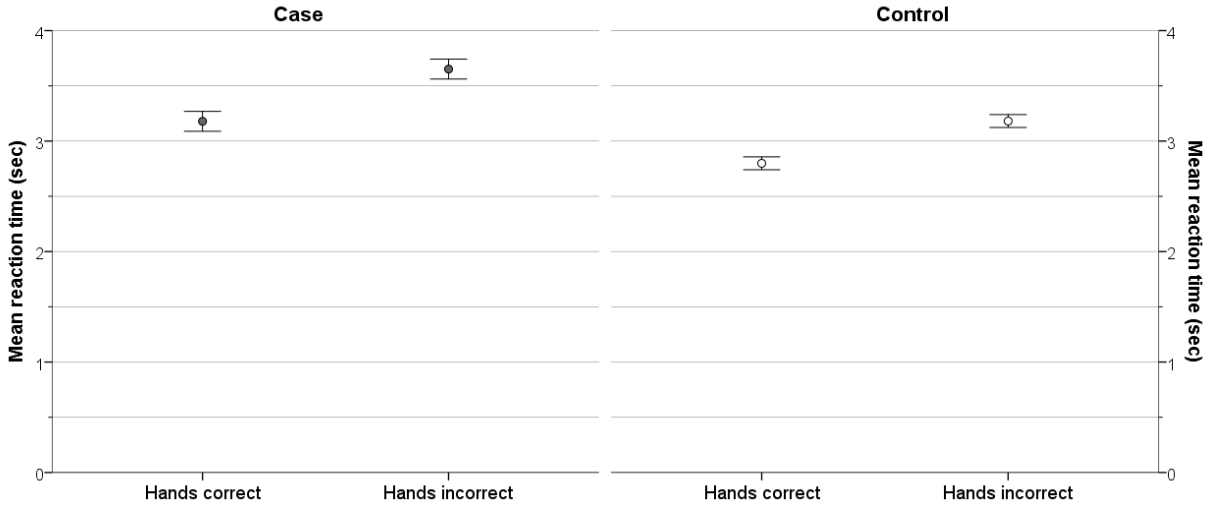


Table 6.61 Laterality discrimination Reaction time hands - Correct v Incorrect statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Correct v Incorrect (sec)	paired t-test	case	0.473	0.293, 0.653	5.26	55	<0.001*	0.33
		control	0.383	0.266, 0.499	6.45	195	<0.001*	0.30

* = statistically significant

6.10.4 Reaction time (back)

The following analyses relate to the time taken to make judgements regarding the direction of trunk movement.

6.10.4.1 Left v Right

Descriptive statistics and distributions are provided in Table 6.62 and

Figure 6.54 to Figure 6.55. Statistical analysis of the difference in reaction times between correct judgements of trunk movement within each group was conducted with a paired-samples t-test (Table 6.63).

For cases, on average, there was little difference in reaction times between images of left and right trunk movement (mean reaction time = 2.08 seconds and 2.14 seconds respectively) and this difference was not statistically significant (mean difference = -0.068 sec; 95% CI -0.17, 0.035; t = -1.31; DF = 57; p = 0.20; *d* = -0.09).

Similarly for controls, on average there was little difference in reaction times between images of left and right trunk movement (mean reaction time = 2.01 seconds and 1.96 seconds respectively) although this difference was statistically significant (mean difference = 0.055 sec; 95% CI 0.01, 0.10; t = 2.44; DF = 196; p = 0.02; *d* = 0.08).

Table 6.62 Laterality discrimination descriptive statistics - Reaction times Left v Right back (sec)

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	L	2.08	0.69	0.091	1.89, 2.26	2.00	1.51, 2.29	1.06	4.95	0
	R	2.14	0.76	0.10	1.94, 2.34	1.91	1.63, 2.48	1.08	4.80	0
control (n=197)	L	2.01	0.72	0.51	1.91, 2.11	1.86	1.51, 2.29	1.00	5.06	0
	R	1.96	0.67	0.48	1.86, 2.05	1.81	1.47, 2.28	1.00	4.97	0

* L = left; R = right

Figure 6.54 Laterality discrimination histograms & boxplots - Reaction times Left v Right back

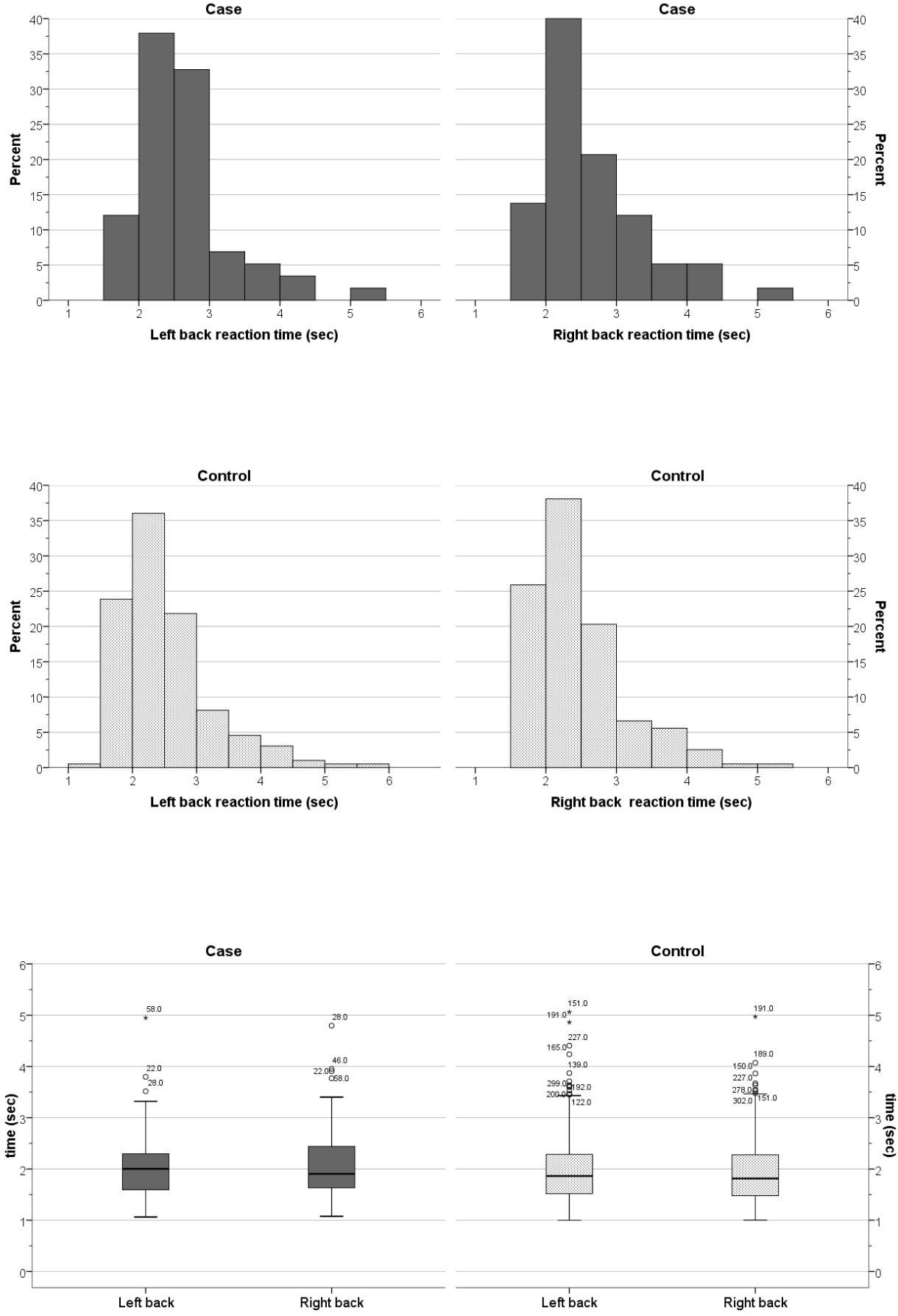


Figure 6.55 Laterality discrimination means (95% CI) - Reaction times Left v Right back

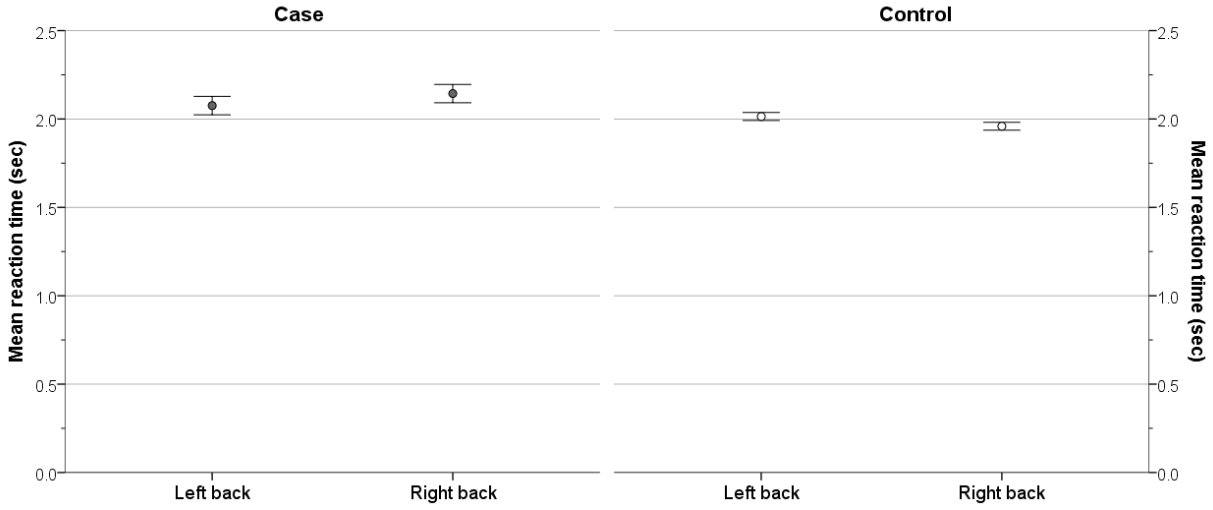


Table 6.63 Laterality discrimination Reaction time Back - Left v Right statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Left v Right (sec)	paired t-test	case	-0.068	-0.172, 0.036	-1.31	57	0.2	-0.09
		control	0.055	0.011, 0.100	2.44	196	0.02*	0.08

* = statistically significant

6.10.4.2 Affected v Unaffected

Descriptive statistics for Affected and Unaffected side are described in Table 6.64 and Figure 6.56 and Figure 6.57. Statistical analysis of the difference in reaction times between trunk images that corresponded to movement towards the Affected and Unaffected side within each group was conducted with a paired-samples t-test (Table 6.65).

For cases, on average, there was little difference in reaction times between the affected or unaffected side (mean reaction time = 2.08 seconds and 2.07 seconds respectively) and this difference was not statistically significant (mean difference = 0.004 sec; 95% CI -0.09, 0.10; t = 0.08; DF = 56; p = 0.94; *d* = 0.01).

Similarly for controls, on average there was little difference between the affected or unaffected side (mean reaction time = 1.97 seconds and 2.01 seconds respectively) and this was also not statistically significant (mean difference = -0.037 sec; 95% CI -0.08, 0.009; t = -1.57; DF = 193; p = 0.12; *d* = -0.05).

Table 6.64 Laterality discrimination descriptive statistics - Reaction time Affected v Unaffected back

	trial*	mean	sd	SE	95% CI	median	min	max	IQR	missing (n)
case (n=57)	A	2.08	0.67	0.09	1.90, 2.25	1.92	1.08	3.95	1.60, 2.34	1 (1.7)
	U	2.07	0.68	0.09	1.89, 2.25	1.97	1.06	4.95	1.60, 2.27	1 (1.7)
control (n=194)	A	1.97	0.66	0.05	1.88, 2.07	1.84	1.05	4.97	1.51, 2.29	3 (1.5)
	U	2.01	0.73	0.05	1.91, 2.11	1.83	1.00	5.06	1.49, 2.29	3 (1.5)

Figure 6.56 Laterality discrimination histograms & boxplots - Reaction time Affected v Unaffected back

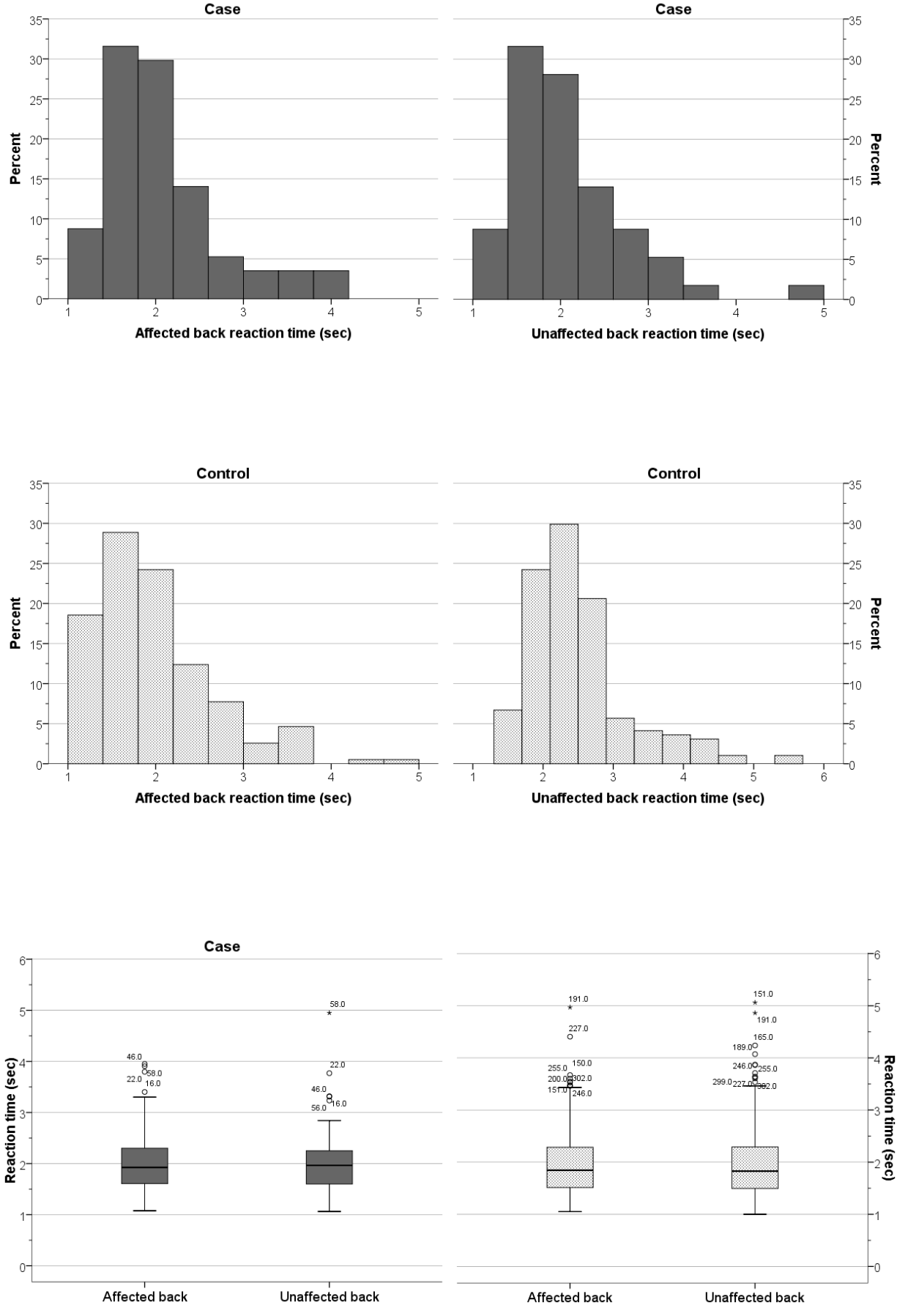


Figure 6.57 Laterality discrimination means (95% CI) - Reaction time Affected v Unaffected back

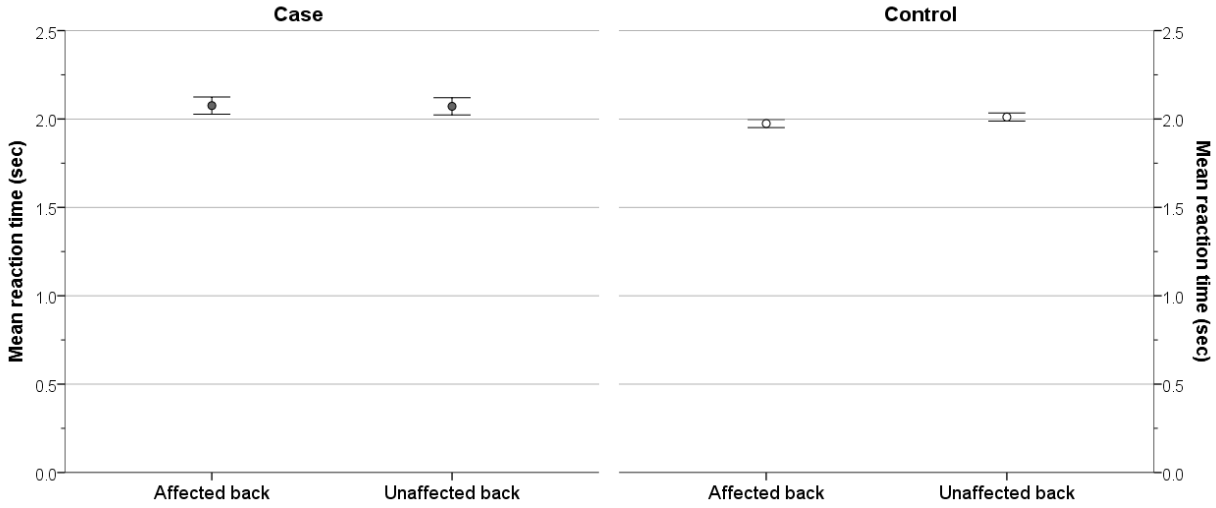


Table 6.65 Laterality discrimination Reaction time back - Affected v Unaffected statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Affected v unaffected	paired t-test	case	0.004	-0.093, 0.101	0.08	56	0.94	0.01
		control	-0.036	-0.082, 0.009	1.57	193	0.120	-0.05

6.10.4.3 Case v Control

Data was combined to form one Case and one Control variable allowing for a direct comparison between the two groups (Table 6.66 and Figure 6.58). An independent-samples t-test was used to test the statistical significance of the difference between groups (Table 6.67).

On average, the mean difference in reaction time for left/right judgements of trunk movement between case and control participants was small (mean reaction time = 2.11 seconds and 1.99 seconds respectively). This difference was not statistically significant (difference in means = 0.123 sec; 95% CI -0.08, 0.32; t = 1.21; df = 253; p = 0.23; *d* = 0.18) suggesting no difference between cases and controls.

A point-biserial correlation was run to determine the relationship between left/right judgement reaction time and group type. Group type was not significantly related to reaction time (r_{pb} = 0.076; 95% BCa CI -0.043, 0.199; p=0.228) and shared only 0.6% of the variability in reaction time for the back (r_{pb}^2=0.006) (Table 6.68).

Table 6.66 Laterality discrimination descriptive statistics - Reaction time Case v Control back (sec)

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	2.11	0.70	0.09	1.93, 2.29	1.97	1.63, 2.28	1.07	4.43	0
control (n=197)	1.99	0.68	0.05	1.89, 2.08	1.80	1.51, 2.26	1.03	4.92	0

Figure 6.58 Laterality discrimination histograms, boxplots & means (95% CI) - Reaction time Case v Control back

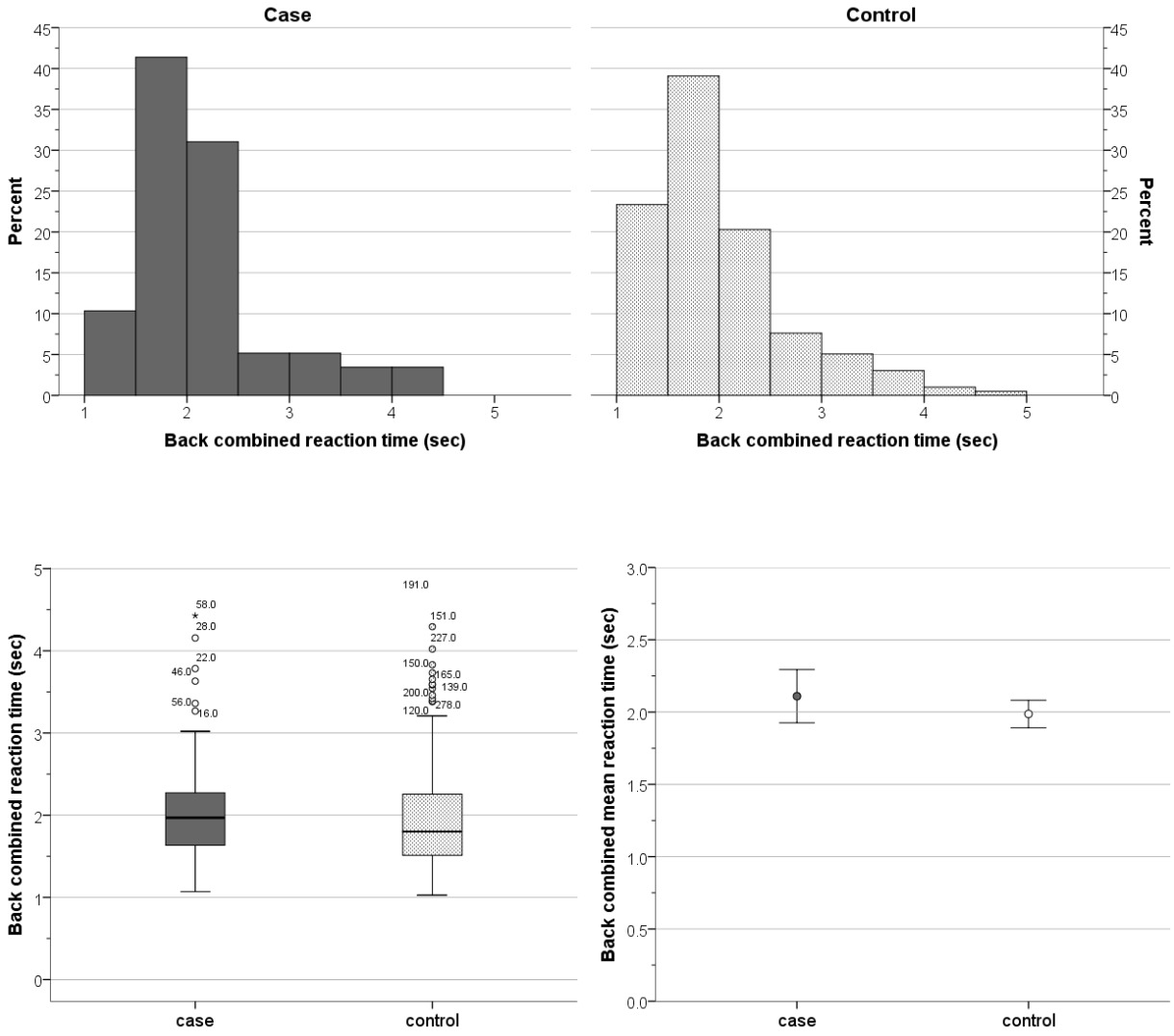


Table 6.67 Laterality discrimination Reaction time Back - case v control statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	side	0.123	-0.078, 0.324	1.21	253	0.23	0.18

Table 6.68 Correlation between Group type and Reaction time (back) - laterality discrimination

analysis	test	outcome variable	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	Reaction time (back)	0.076	-0.043, 0.199	0.006	0.228

6.10.4.4 Correct v Incorrect

Descriptive statistics for correct and incorrect reaction times for left/right judgements of trunk movement are described in Table 6.69 and Figure 6.59 and Figure 6.60. Statistical analysis of the difference in reaction times between correct and incorrect judgements within each group was conducted with a paired-samples t-test (Table 6.70).

For cases, on average, there was over a 1 second difference in reaction times between correct and incorrect judgements (mean reaction time = 2.11 seconds and 3.27 seconds respectively) and this difference was statistically significant (mean difference = -1.16 sec; 95% CI -0.83, -1.49; t = -7.07; DF = 57; p<0.001; *d* = -0.99).

For controls, on average there was a similar but smaller difference between correct and incorrect reaction times (mean reaction time = 1.99 seconds and 2.86 seconds respectively) and this was also statistically significant (mean difference = -0.86 sec; 95% CI -0.73, -0.99; t = -13.37; DF = 194; p<0.001; *d* = -0.85).

Table 6.69 Laterality discrimination descriptive statistics - Reaction times Correct v Incorrect back (sec)

	trial*	n	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case	C	58	2.11	0.70	0.09	1.93, 2.29	1.97	1.63, 2.28	1.07	4.43	0
	I	58	3.27	1.53	0.20	2.87, 3.67	2.97	2.15, 3.76	1.14	7.78	0
control	C	197	1.99	0.68	0.05	1.89, 2.08	1.80	1.51, 2.26	1.03	4.92	0
	I	195	2.86	1.27	0.09	2.68, 3.04	2.47	1.94, 3.48	1.06	7.67	2

* C = correct; I = incorrect

Figure 6.59 Laterality discrimination histograms & boxplots - Reaction times Correct v Incorrect back

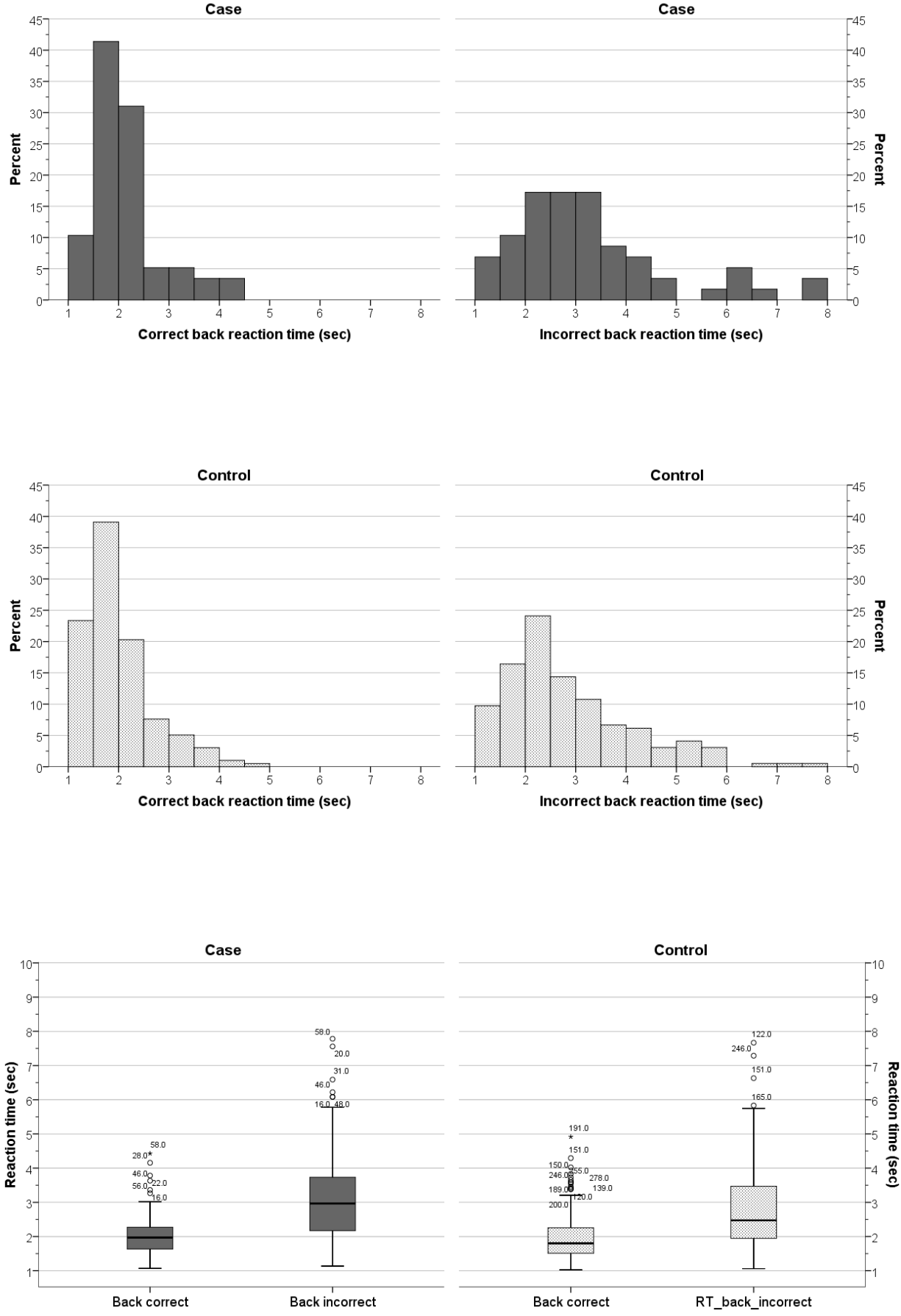


Figure 6.60 Laterality discrimination means (95% CI) - Reaction times Correct v Incorrect back

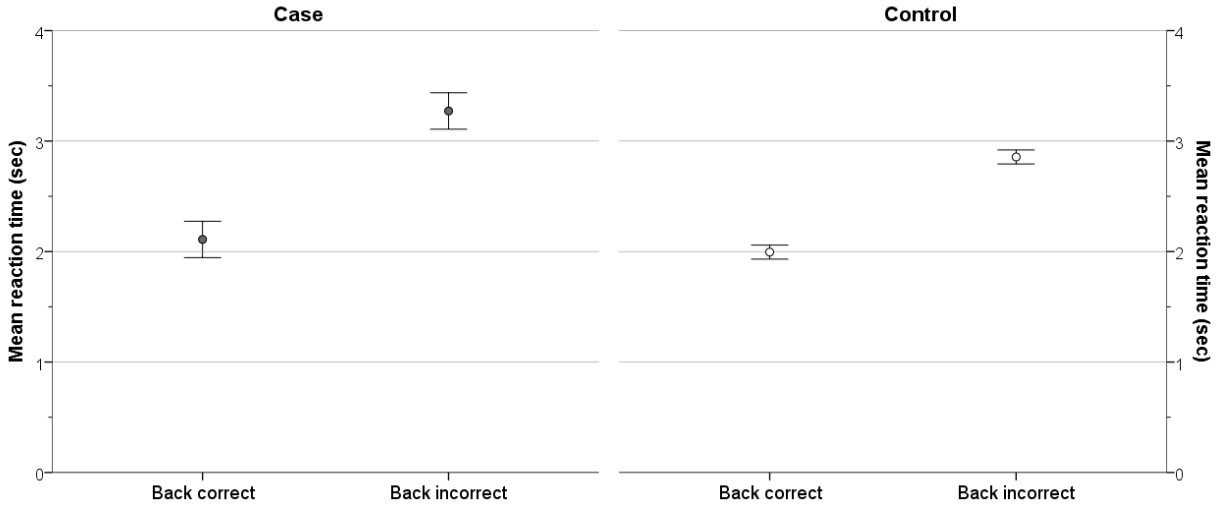


Table 6.70 Laterality Discrimination Reaction time Back - Correct v Incorrect statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Correct v Incorrect (sec)	paired t-test	case	1.162	0.833, 1.492	7.07	57	<0.001*	0.99
		control	0.860	0.734, 0.987	13.37	194	<0.001*	0.85

* = statistically significant

6.11 Line bisection testing

6.11.1 Left v right hand

Participants completed 12 trials with the right hand and 12 with the left hand. Individual trials were then combined to form Right-hand and Left-hand variables for each group (Table 6.71 and

Figure 6.61 and Figure 6.62). Absolute errors were adjusted (AEadjusted) to take into account the differences in line length between tests (Appendix 18).

Statistical analysis of the difference between left and right mean $AE_{adjusted}$ within each group was conducted with a paired-samples t-test (Table 6.72).

For cases, on average, there was little difference in $AE_{adjusted}$ between tests performed with the right and left hands (mean $AE_{adjusted}$ = 2.21% and 2.35% respectively) and this difference was not statistically significant (mean difference = -0.14 %; BCa 95% CI -0.39, 0.12; t = -1.07; DF = 57; p = 0.289; *d* = -0.15).

Similarly for controls, on average there was little difference between tests performed with the right and left hands (mean $AE_{adjusted}$ = 2.06% and 2.36% respectively). However, this difference was statistically significant (mean difference = -0.25 %; 95% CI -0.38, -0.13; t = -4.04; DF = 195; p < 0.001; *d* = -0.33).

Table 6.71 Line bisection descriptive statistics - Right v left within groups

	side*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Case (n=58)	RH	2.21	0.86	0.11	1.99, 2.44	2.13	1.73, 2.56	0.73	5.61	0
	LH	2.35	1.01	0.13	2.08, 2.61	2.12	1.69, 2.98	1.03	6.07	0
Controls (n=196)	RH	2.06	0.68	0.05	1.97, 2.16	1.95	1.62, 2.36	0.75	5.18	1
	LH	2.36	1.02	0.07	2.21, 2.50	2.25	1.78, 2.66	0.66	10.09	1

Figure 6.61 Line bisection histograms & boxplots - Right v left within groups

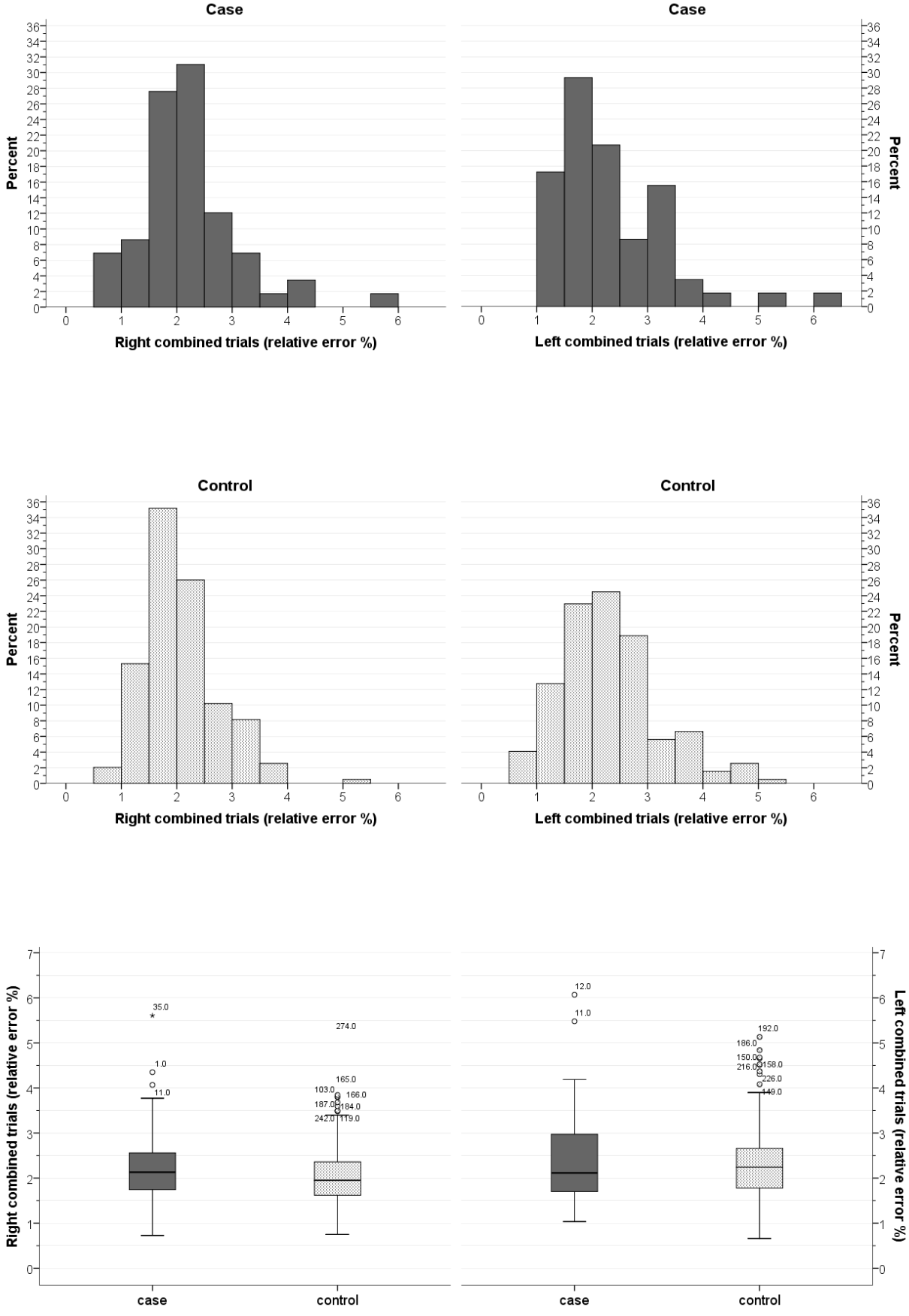


Figure 6.62 Line bisection means (95% CI) - Right v left within groups

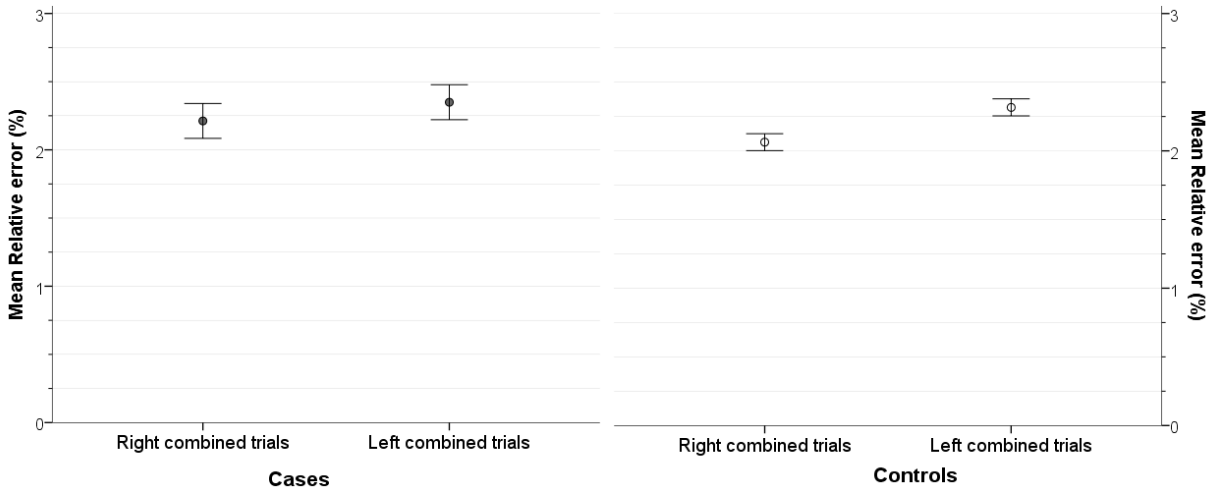


Table 6.72 Line bisection Left v Right hand - results of statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
left v right hand	paired t-test	case	-0.14	-0.39, 0.12	-1.07	57	0.289	-0.15
		control	-0.25	-0.38, -0.13	-4.036	195	<0.001*	-0.33

* = statistically significant

6.11.2 Test paper position - Left v Centre v Right

Participants completed 8 trials each with the test paper centred in front of them, to the left of centre, and to the right of centre. Individual trials were combined to form 3 variables relating to the positioning of the paper (Left, Centre and Right paper position) for each group (Table 6.73 and Figure 6.63 to Figure 6.64).

Differences between mean $AE_{adjusted}$ for each test position were small for both case and control participants (0.04 to 0.23% and 0.09 to 0.24% respectively). A within-group statistical analysis of the difference between mean $AE_{adjusted}$ for each test position was conducted with a one-way repeated-measures ANOVA (Table 6.74).

For cases, Mauchly's test indicated that the assumption of sphericity had been violated (χ^2 = 17.56; df = 2; p <0.001), therefore Huynh-Feldt corrected tests are reported (ε = 0.81). The results show that the mean $AE_{adjusted}$ when estimating midline was not affected by the position of the test paper (F = 1.70, df_m = 1.61; df_r = 91.94; p = 0.193; ω^2 = 0.53).

For controls, Mauchly's test indicated that the assumption of sphericity was valid (χ^2 = 1.39; df = 2; p = 0.50), therefore no corrections were applied. The results show that the mean $AE_{adjusted}$ when estimating midline was affected by the position of the test paper (F = 6.77, df_m = 2; df_r = 390; p = 0.001; ω^2 = 0.91).

Post hoc analysis of control participant data revealed statistically significant differences for trials with the test paper in the left versus the centre position (difference in means = 0.24%; Bonferroni-corrected 95% CI 0.08, 0.40; p = 0.001). This suggests that when the test was conducted with the paper in the left position, control participants were less accurate in identifying the midline as compared to the centre position. No statistically significant difference was revealed for left versus right or centre versus right positions.

Table 6.73 Line bisection descriptive statistics - Test paper position relative error (%)

	trial*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	L	2.23	0.82	0.11	2.02, 2.45	2.10	1.55, 2.67	0.92	5.25	0
	C	2.19	0.86	0.11	1.96, 2.42	2.14	1.42, 2.64	1.00	4.81	0
	R	2.42	1.24	0.16	2.10, 2.75	2.15	1.58, 3.00	0.67	6.48	0
control (n=196)	L	2.32	0.89	0.06	2.19, 2.44	2.20	1.66, 2.83	0.76	5.78	1
	C	2.08	0.81	0.06	1.97, 2.19	2.00	1.48, 2.56	0.50	5.22	1
	R	2.17	0.78	0.06	2.06, 2.28	2.07	1.57, 2.66	0.78	5.01	1

Table 6.74 Line bisection Test paper position - results of statistical analyses

analysis	test		type (ε)	F	df_M	df_R	p-value	ω^2
paper position L v C v R	repeated-measures ANOVA	case	HF (0.81)	1.70	1.61	91.94	0.19	0.53
		control	SA	6.77	2	390	0.001*	0.91

* = statistically significant; HF = Huynh-Feldt estimate of sphericity; SA = sphericity assumed

Figure 6.63 Line bisection histograms - test paper position within groups

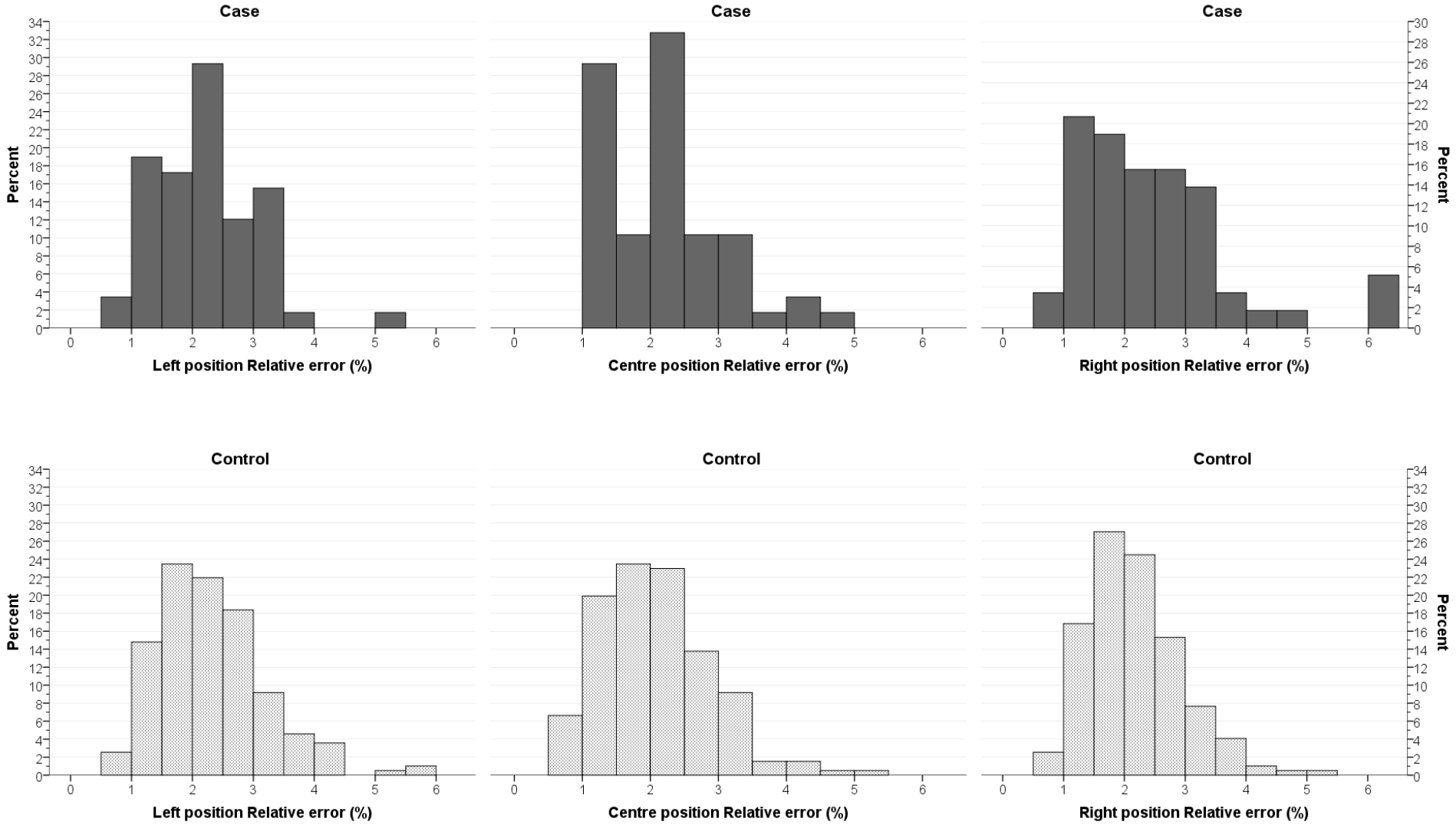
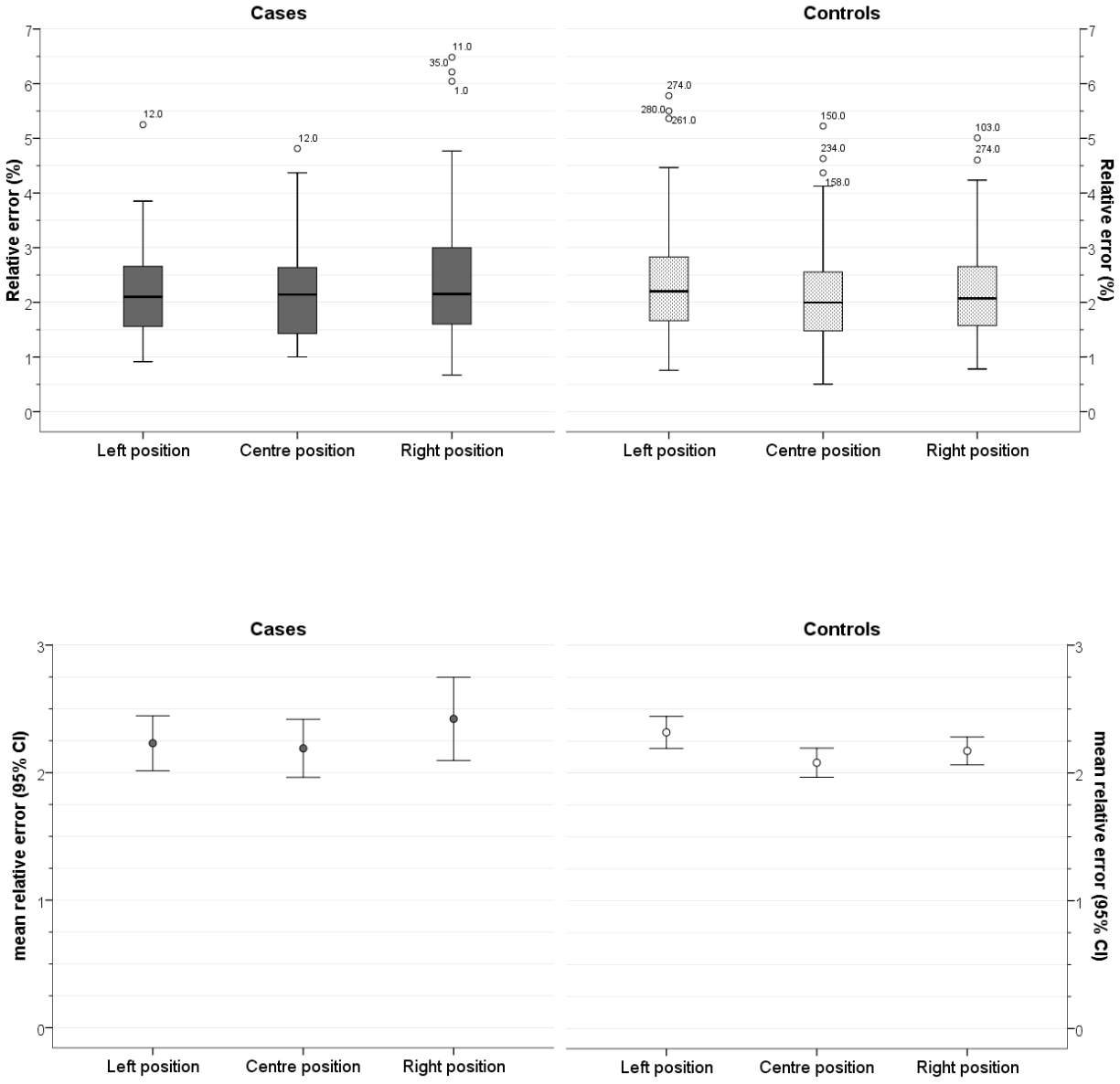


Figure 6.64 Line bisection boxplots and means (95% CI) - test paper position within groups



6.11.3 Line length - 200mm v 225mm v 250mm

Participants were tested 6 times each using lines of 3 different lengths (200mm, 225mm and 250mm). Individual trials were combined to form 3 separate variables for each group (Table 6.75 and Figure 6.65 to Figure 6.66).

Examination of the distributions revealed an extreme score amongst cases for the 225mm line condition. Their $AE_{adjusted}$ score of 9.63% was twice the value of the next highest case participant (4.78%). Therefore, their result for this condition was classified as an outlier and excluded from further analysis.

Differences between mean $AE_{adjusted}$ for each line length were small for both case and control participants (0.02 to 0.06% and 0.02 to 0.12% respectively). Statistical analysis was conducted with a one-way repeated-measures ANOVA (Table 6.76).

For cases, Mauchly's test indicated that the assumption of sphericity had been violated (χ^2 = 7.02; df = 2; p = 0.03), therefore Huynh-Feldt corrected tests are reported (ε = 0.92). The results show that the mean $AE_{adjusted}$ when estimating midline was not affected by line length (F = 0.03, df_m = 1.84; df_r = 103.09; p = 0.968; ω^2 = -0.005).

For controls, Mauchly's test indicated that the assumption of sphericity was valid (χ^2 = 2.65; df = 2; p = 0.27), therefore no corrections were applied. The results show that the mean $AE_{adjusted}$ when estimating midline was also not affected by the length of the line (F = 1.06, df_m = 2; df_r = 390; p = 0.348; ω^2 = 0.11).

Table 6.75 Line bisection descriptive statistics - Line length $AE_{adjusted}$ (%)

	trial	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	200mm	2.45	1.25	0.16	2.12, 2.78	2.32	1.46, 3.06	0.67	6.61	0
	225mm	2.54	1.32	0.17	2.19, 2.88	2.38	1.67, 2.96	0.97	9.63	0
	225 - outlier	2.41	0.92	0.12	2.17, 2.66	2.38	1.65, 2.93	0.97	4.78	1
	250mm	2.47	1.02	0.13	2.20, 2.73	2.43	1.54, 3.34	0.74	4.42	0
control (n=196)	200mm	2.46	1.13	0.08	2.30, 2.62	2.29	1.75, 2.84	0.54	7.17	1
	225mm	2.36	1.00	0.07	2.21, 2.50	2.17	1.67, 2.92	0.69	7.31	1
	250mm	2.34	0.93	0.07	2.21, 2.47	2.18	1.63, 2.99	0.40	4.67	1

Table 6.76 Line bisection Line lengths - results of statistical analyses

analysis	test		type (ε)	F	df_M	df_R	p-value	ω^2
line length 200 v 225 v 250	repeated-measures ANOVA	case	HF (0.92)	0.03	1.841	103.09	0.968	-0.005
		control	SA	1.059	2	390	0.348	0.11

* = statistically significant; HF = Huynh-Feldt estimate of sphericity; SA = sphericity assumed

Figure 6.65 Line bisection histograms - line length within groups

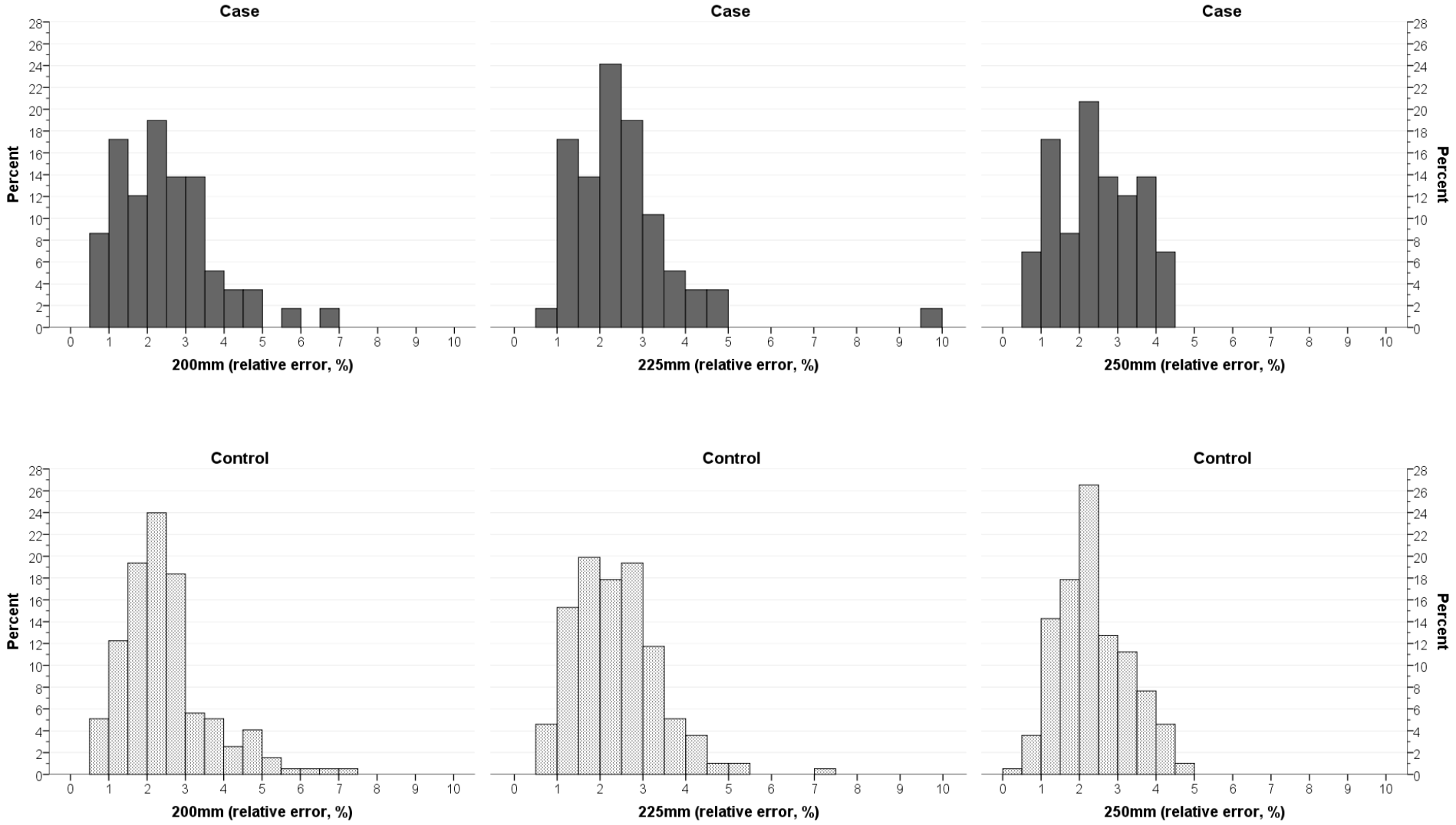
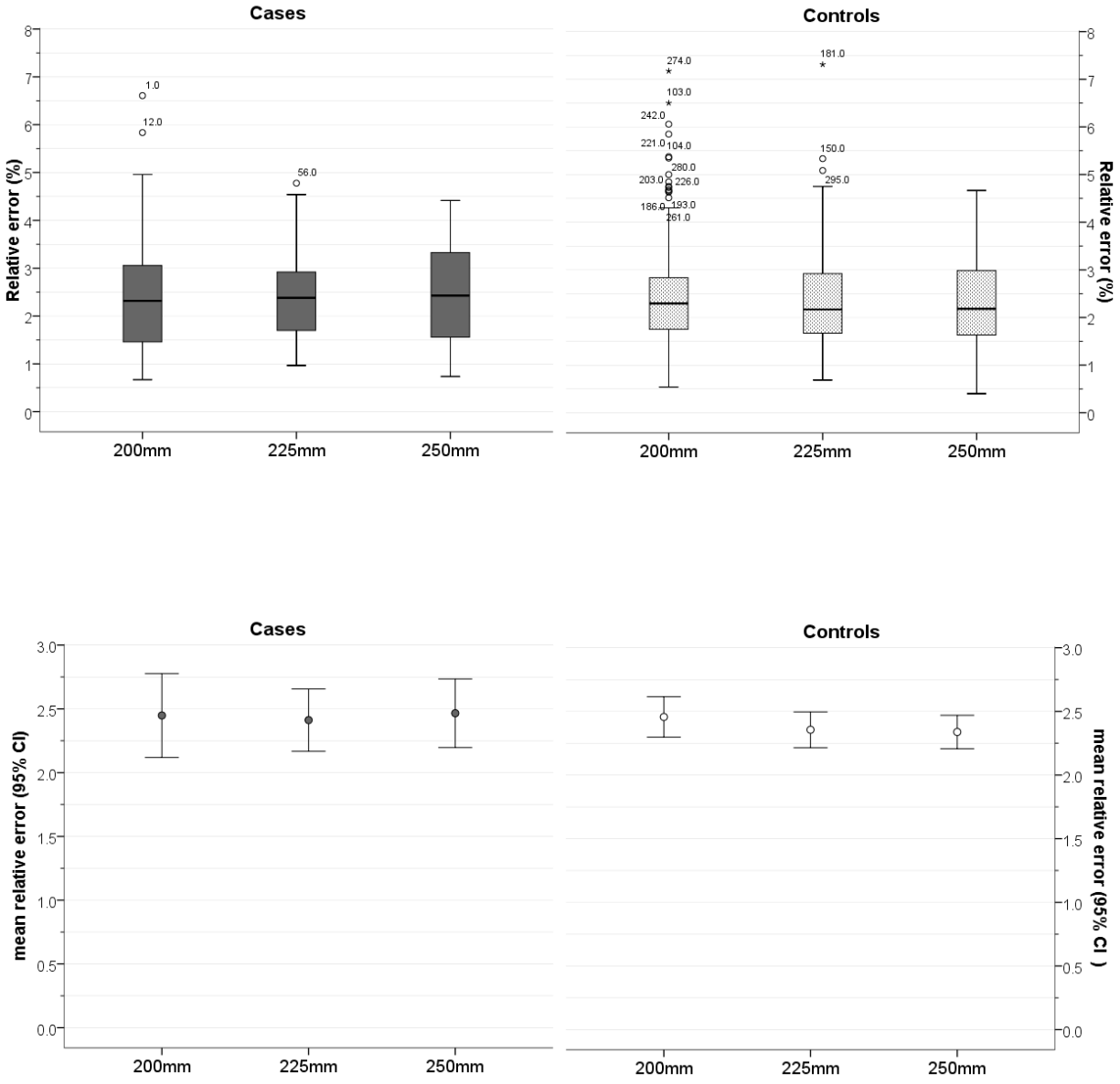


Figure 6.66 Line bisection boxplots and means (95% CI) - Line length within groups (outlier excluded)



6.11.4 Affected v unaffected side

Mean $AE_{adjusted}$ in determining the midline was analysed taking into account the curve direction for cases and the corresponding side for the matched controls. This involved recoding each of the 24 initial trials into affected (i.e. the direction of curve) and unaffected sides with respect to both the hand that was used, and the position of the test paper. For example, for cases, if the curve was convex to the right, then the 12 trials using the right hand were reclassified as 'Affected side' and 12 trials using the left hand classified as 'Unaffected side'. The reverse occurred for curves convex to the left. Controls adopted the same classification as their matched case.

The same procedure was used to create Affected and Unaffected side variables with respect to the position of the test paper (only 8 trials each as data from centre position excluded). Results for these sets of variables are described below under the appropriate headings.

a) Hand used

Descriptive statistics for Affected and Unaffected side (with respect to which hand was used to complete the task) are described in Table 6.77 and Figure 6.67 and Figure 6.68). One case was missing x-ray information so was unable to be categorised according to curve direction, along with the 3 matched control participants. A further case failed to complete the line bisection test.

Statistical analysis of the difference between Affected and Unaffected mean $AE_{adjusted}$ within each group was conducted with a paired-samples t-test (Table 6.78).

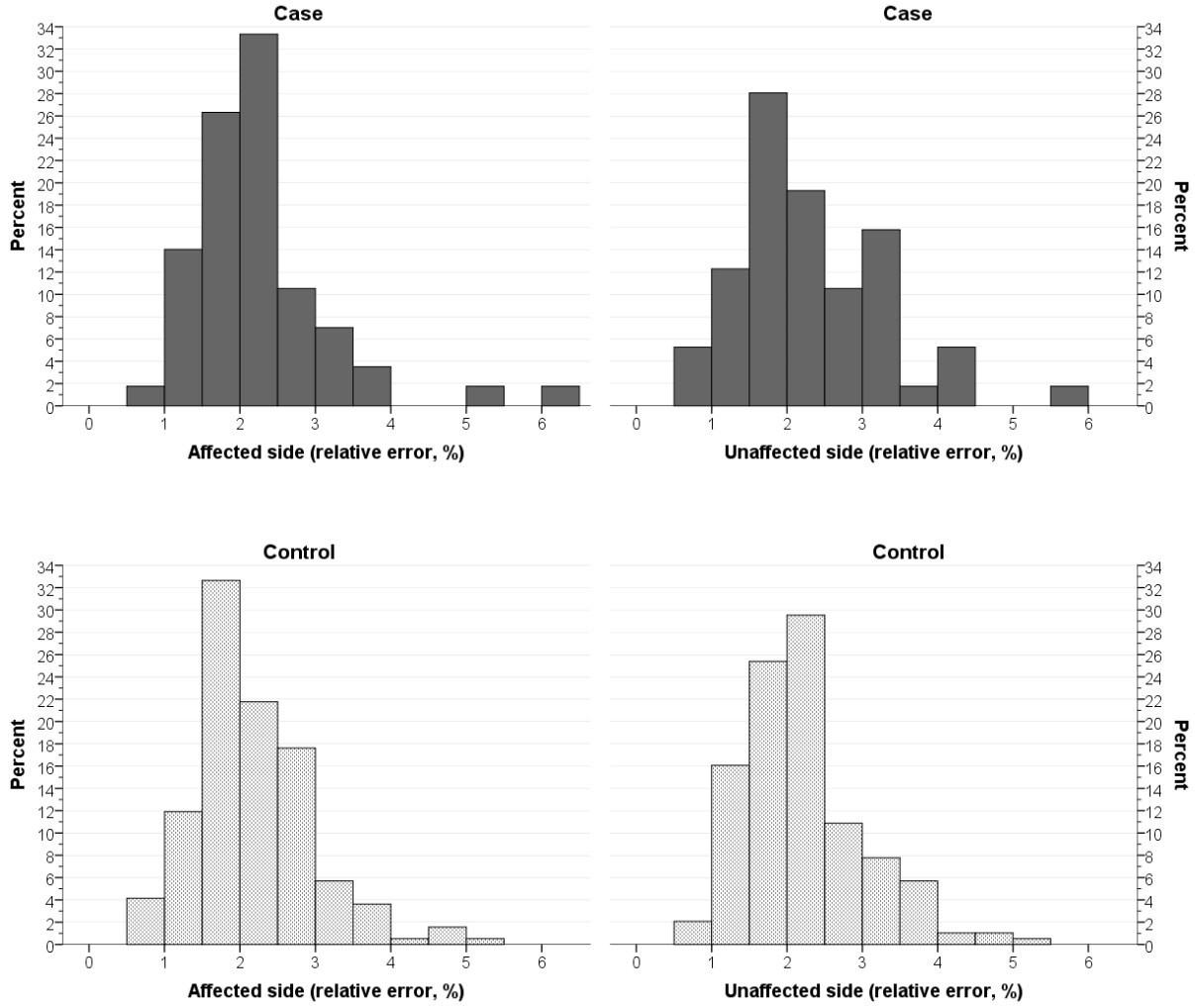
For cases, on average, there was little difference in $AE_{adjusted}$ between tests using the hand corresponding to the affected or unaffected side (mean $AE_{adjusted}$ = 2.25% and 2.34% respectively) and this difference was not statistically significant (mean difference = -0.09 %; 95% CI -0.35, 0.18; t = -0.67; DF = 56; p = 0.508; *d* = -0.09).

Similarly for controls, on average there was little difference between tests performed with the hand corresponding to the affected or unaffected side (mean $AE_{adjusted}$ = 2.16% and 2.22% respectively). This difference was also not statistically significant (mean difference = -0.06 %; 95% CI -0.19, 0.07; t = -0.88; DF = 192; p = 0.38; *d* = -0.07).

Table 6.77 Line bisection descriptive statistics- Affected v unaffected (hand) within groups

	trial	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Case (n=57)	A	2.25	0.92	0.12	2.00, 2.50	2.11	1.76, 2.51	1.00	6.07	1
	U	2.34	0.96	0.13	2.08, 2.59	2.25	1.69, 2.99	0.73	5.61	1
Control (n=193)	A	2.16	0.78	0.06	2.05, 2.27	2.04	1.65, 2.58	0.75	5.18	4
	U	2.22	0.79	0.06	2.11, 2.33	2.12	1.75, 2.53	0.66	5.13	4

Figure 6.67 Line bisection histograms & boxplots - affected v unaffected (hand) within groups



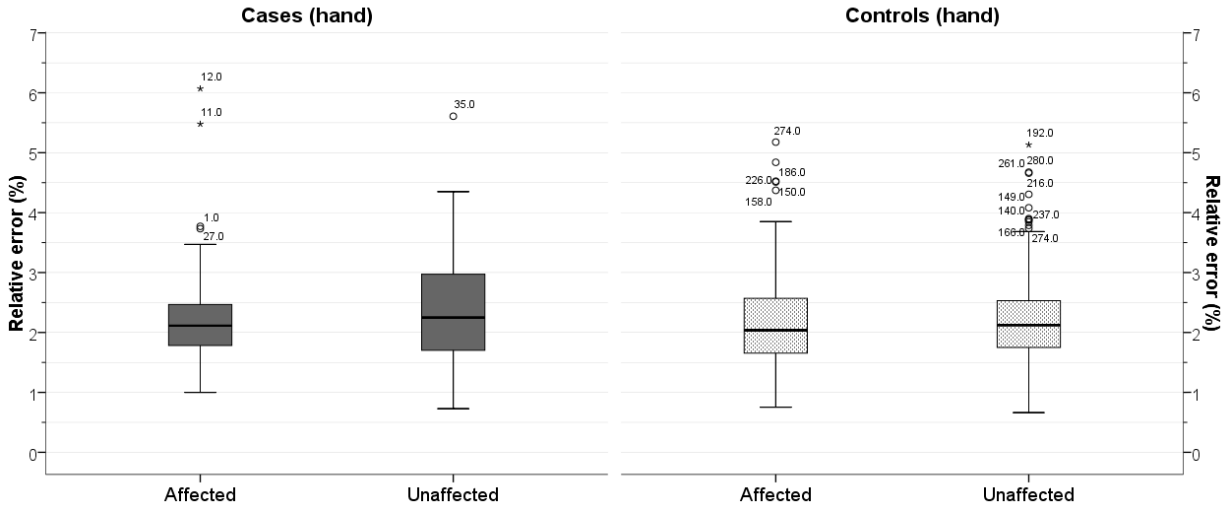


Figure 6.68 Line bisection means (95% CI) - Affected v unaffected sides (hand)

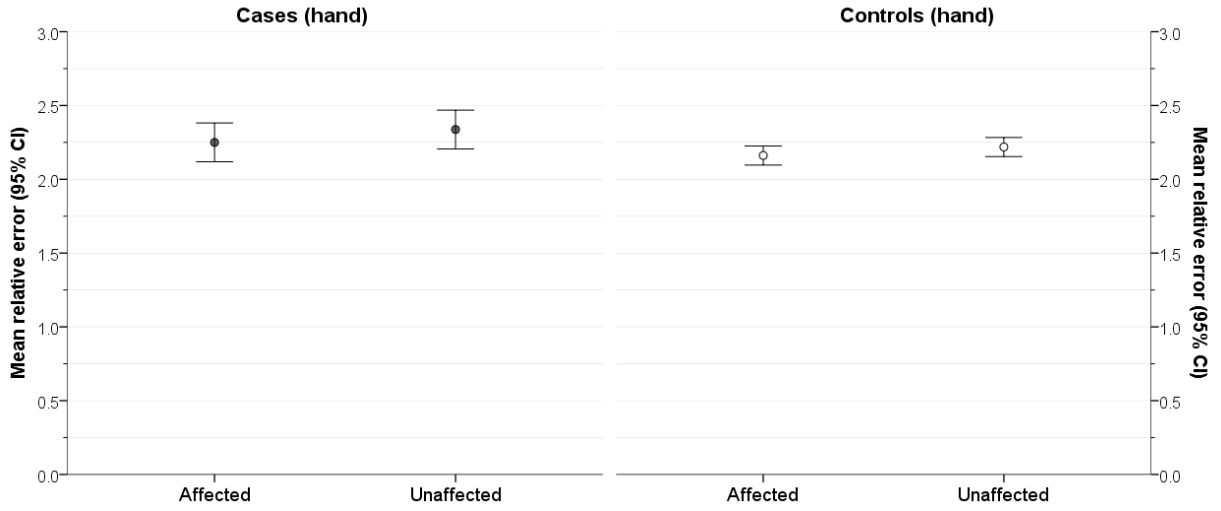


Table 6.78 Line bisection Affected v Unaffected Hand - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
affected v unaffected (hand)	paired t-test	case	-0.09	-0.35, 0.18	-0.67	56	0.508	-0.09
		control	-0.06	-0.19, 0.07	-0.88	192	0.38	-0.07

(b) Test paper position

Descriptive statistics for Affected and Unaffected side (with respect to the positon of the test paper) are described in Table 6.79 and Figure 6.69 and Figure 6.70). One case and four control participants were not included in this due to missing data (see previous section).

Statistical analysis of the difference between Affected and Unaffected mean $AE_{adjusted}$ within each group was conducted with a paired-samples t-test (Table 6.80).

For cases, on average, there was little difference in $AE_{adjusted}$ between tests with the paper position corresponding to the affected or unaffected side (mean $AE_{adjusted}$ = 2.35% and 2.32% respectively) and this difference was not statistically significant (mean difference = 0.03%; 95% CI -0.30, 0.36; t = 0.20; DF = 56; p = 0.843; *d* = 0.03).

Similarly for controls, on average there was little difference between tests performed with the paper position corresponding to the affected or unaffected side (mean $AE_{adjusted}$ = 2.23% and 2.25% respectively). This difference was also not statistically significant (mean difference = -0.02 %; 95% CI -0.15, 0.12; t = -0.25; DF = 192; p = 0.803; *d* = -0.02).

Table 6.79 Line bisection descriptive statistics- Affected v unaffected (paper position) within groups

	trial	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Case (n=57)	A	2.35	0.89	0.12	2.12, 2.59	2.31	1.79, 2.74	0.96	5.25	1
	U	2.32	1.21	0.16	2.00, 2.64	2.01	1.55, 3.00	0.67	6.48	1
Control (n=193)	A	2.23	0.78	0.06	2.12, 2.34	2.14	1.69, 2.82	0.79	5.01	4
	U	2.25	0.9	0.06	2.12, 2.37	2.04	1.59, 2.70	0.76	5.78	4

Figure 6.69 Line bisection histograms & boxplots - Affected v unaffected (paper position) within groups

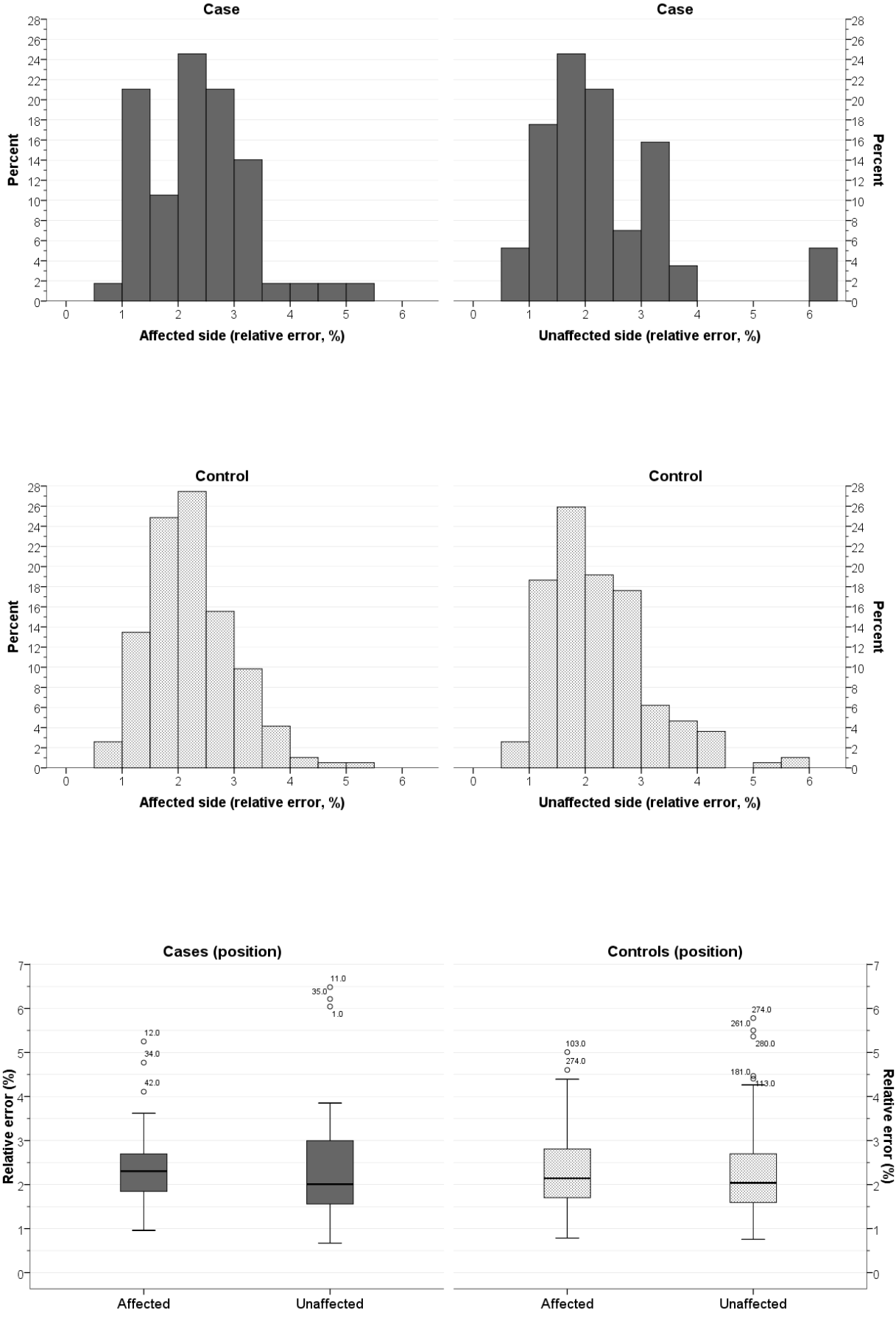


Figure 6.70 Line bisection means (95% CI) - Affected v unaffected (paper position) within groups

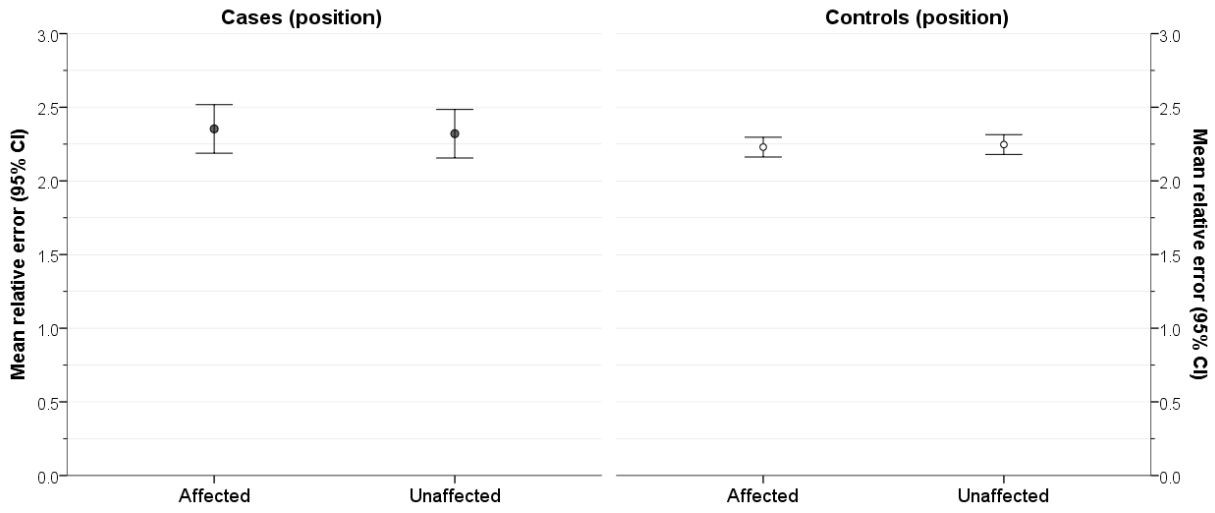


Table 6.80 Line bisection Affected v Unaffected (paper position) - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
affected v unaffected (position)	paired t-test	case	0.03	-0.30, 0.36	0.20	56	0.843	0.03
		control	-0.02	-0.15, 0.12	-0.25	192	0.803	-0.02

6.11.5 Body line v standard lines

Participants completed 18 trials with standard test lines and 6 using lines drawn within the shape of a human torso. Individual trials were then combined to form Standard lines and Body line variables for each group (Table 6.81 and Figure 6.71 and Figure 6.72). Statistical analysis of the difference between mean $AE_{adjusted}$ for standard and body lines within each group was conducted with a paired-samples t-test (Table 6.82).

For cases, on average, there was a small difference in $AE_{adjusted}$ between tests performed using either the standard or the body lines (mean $AE_{adjusted}$ = 2.48% and 1.67% respectively) and this difference was statistically significant (mean difference = 0.81 %; 95% CI 0.60, 1.02; t = 7.76; DF = 57; p <0.001; *d* = 0.99).

For controls, on average there was a similar difference between tests performed using either the standard or the body lines (mean $AE_{adjusted}$ = 2.38% and 1.61% respectively). This difference was also statistically significant (mean difference = 0.77 %; 95% CI 0.67, 0.88; t = 15.05; DF = 195; p < 0.001; *d* = 1.13).

Table 6.81 Line bisection descriptive statistics - Body v standard lines within groups

	trial	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Case (n=58)	body	1.67	0.73	0.10	1.48, 1.86	1.63	1.15, 2.03	0.49	5.04	0
	standard	2.48	0.91	0.12	2.24, 2.72	2.27	1.91, 2.96	1.04	5.43	0
Control (n=196)	body	1.61	0.63	0.04	1.52, 1.70	1.56	1.13, 2.06	0.44	3.13	1
	standard	2.38	0.74	0.05	2.28, 2.49	2.32	1.88, 2.72	0.97	5.26	1

Figure 6.71 Line bisection histograms & boxplots - Body v standard lines within groups

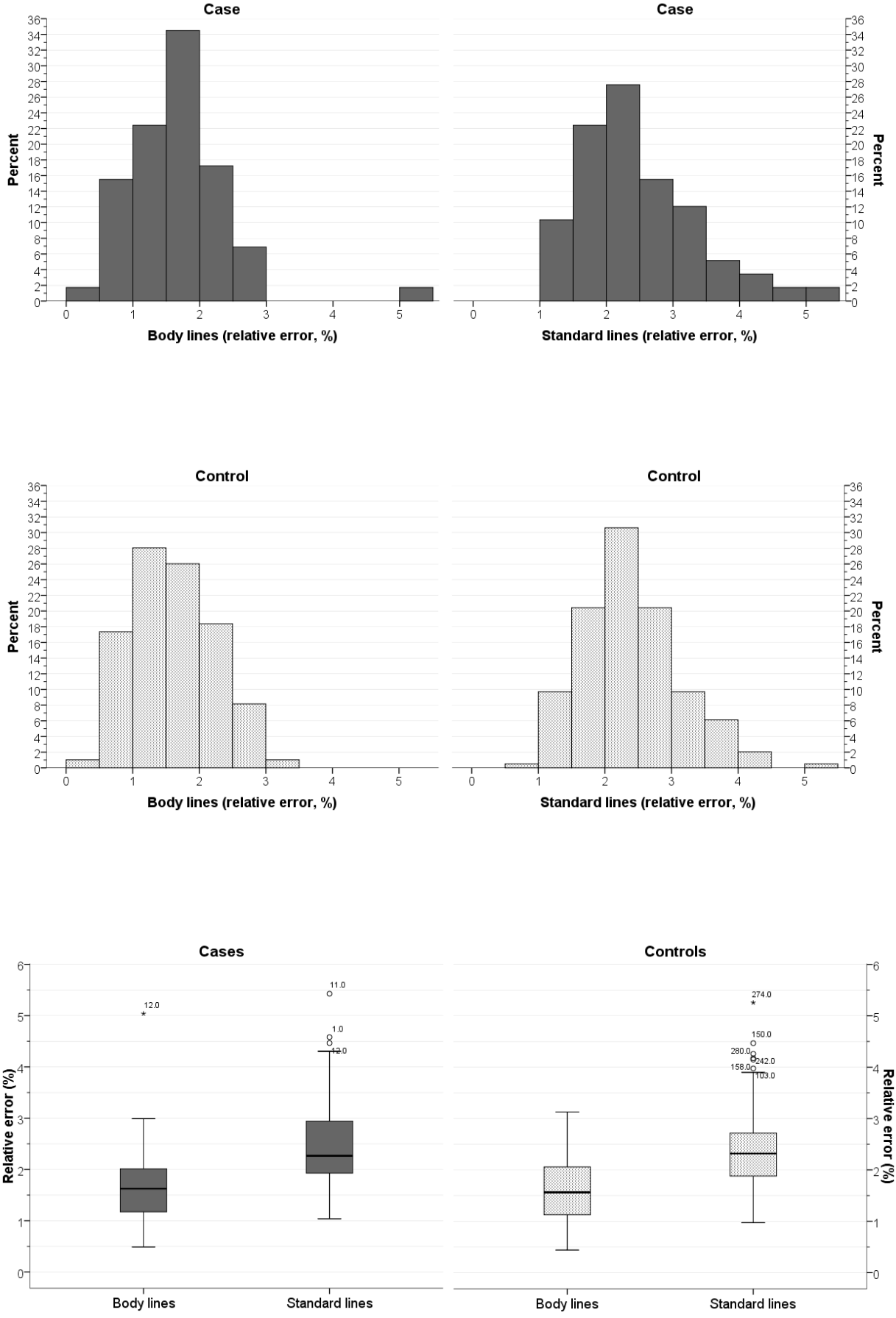


Figure 6.72 Line bisection means (95%CI) - body v standard lines within groups

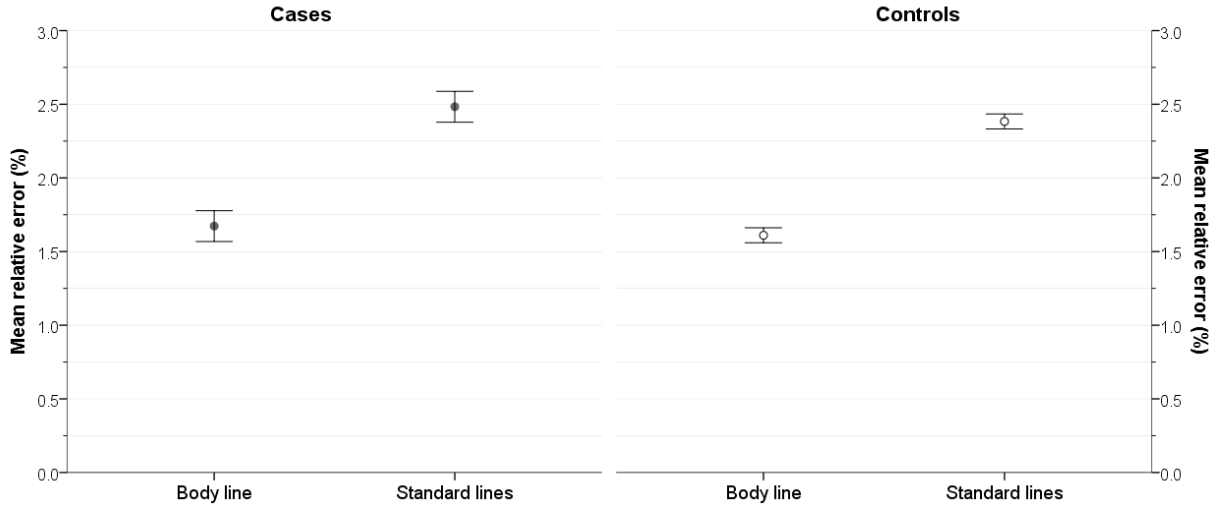


Table 6.82 Line bisection body v standard lines - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
body v standard lines	paired t-test	case	0.81	0.60, 1.02	7.76	57	<0.001*	0.99
		control	0.77	0.67, 0.87	15.05	195	<0.001*	1.13

* = statistically significant

6.11.6 Case v control

As the differences in $AE_{adjusted}$ within groups was small and generally not statistically significant, all trials were combined to form one Case and one Control $AE_{adjusted}$ variable allowing for a direct comparison between the two groups. The distribution of both groups was relatively consistent with a normal distribution although a slight positive skew was present (Table 6.83 and Figure 6.73). An independent-samples t-test was used to test the statistical significance of the difference between groups (Table 6.84).

On average, the mean difference in $AE_{adjusted}$ between case and control participants was small (mean $AE_{adjusted}$ = 2.28% and 2.19% respectively) and this difference was not statistically significant (difference in means = 0.091%; 95% CI -0.11, 0.29; t = 0.893; df = 252; p = 0.37; *d* = 0.14).

A point-biserial correlation was run to determine the relationship between line bisection error and group type. Group type was not significantly related to $AE_{adjusted}$ (r_{pb} = 0.054; 95% BCa CI -0.083, 0.183; p=0.392) and shared only 0.3% of the variability in line bisection error (r_{pb}^2=0.003) (Table 6.85).

Table 6.83 Line bisection descriptive statistics- Case v control combined $AE_{adjusted}$ (%)

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=58)	2.28	0.80	0.10	2.07, 2.49	2.16	1.76, 2.66	1.03	4.77	0
control (n=196)	2.19	0.64	0.05	2.10, 2.28	2.08	1.77, 2.53	0.84	4.46	1

Figure 6.73 Line bisection histograms, boxplots and means (95% CI) - Case v control

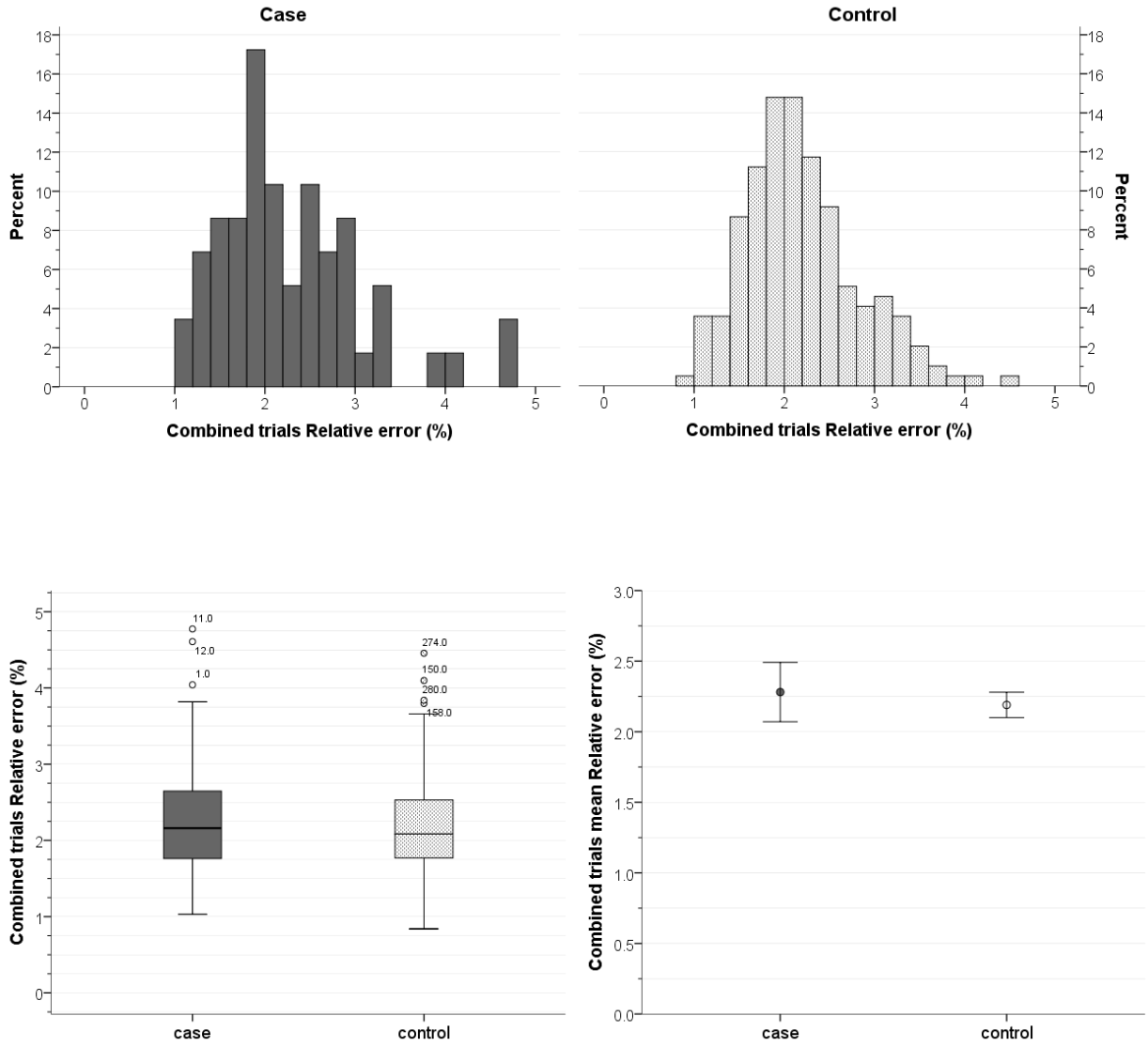


Table 6.84 Line bisection Case v Control - statistical analyses

analysis	test	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	0.09	-0.11, 0.29	0.893	252	0.373	0.14

Table 6.85 Correlation between Group type and Line bisection error

analysis	test	outcome variable	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	biserial correlation	line bisection error	0.054	-0.083, 0.183	0.003	0.392

6.12 Trunk proprioception (position matching)

6.12.1 Left v Right

Descriptive statistics and distributions are provided in Table 6.86 and Figure 6.74 to Figure 6.75. Statistical analysis of the difference between left and right side-flexion position matching ability within each group was conducted with a paired-samples t-test (Table 6.87).

For cases, on average, there was little difference in $AE_{adjusted}$ between tests performed to the left and right side (mean $AE_{adjusted}$ = 11.01% and 10.15% respectively) and this difference was not statistically significant (mean difference = 0.87%; 95% CI -1.38, 3.11; t = 0.77; DF = 57; p = 0.44; *d* = 0.13).

Similarly for controls, on average there was little difference between tests performed to the left and right sides (mean $AE_{adjusted}$ = 9.37% and 9.95% respectively) and this difference was also not statistically significant (mean difference = -0.58; 95% CI -1.86, 0.70; t = -0.9; DF = 195; p = 0.37; *d* = -0.08).

Table 6.86 Trunk proprioception descriptive statistics - Left v Right-combined tests ($AE_{adjusted}$ %)

	side	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Case (n=58)	L	11.01	6.81	0.89	9.22, 12.81	9.71	6.17, 15.85	0	32.54	0
	R	10.15	6.34	0.83	8.48, 11.81	9.26	6.41, 14.09	0	38.28	
Control (n=196)	L	9.37	6.56	0.47	8.45, 10.29	8.44	4.31, 12.76	0	31.75	1
	R	9.95	7.55	0.54	8.89, 11.02	7.97	4.47, 13.5	0	35.70	

Figure 6.74 Trunk proprioception histograms & boxplots - Left v Right combined tests

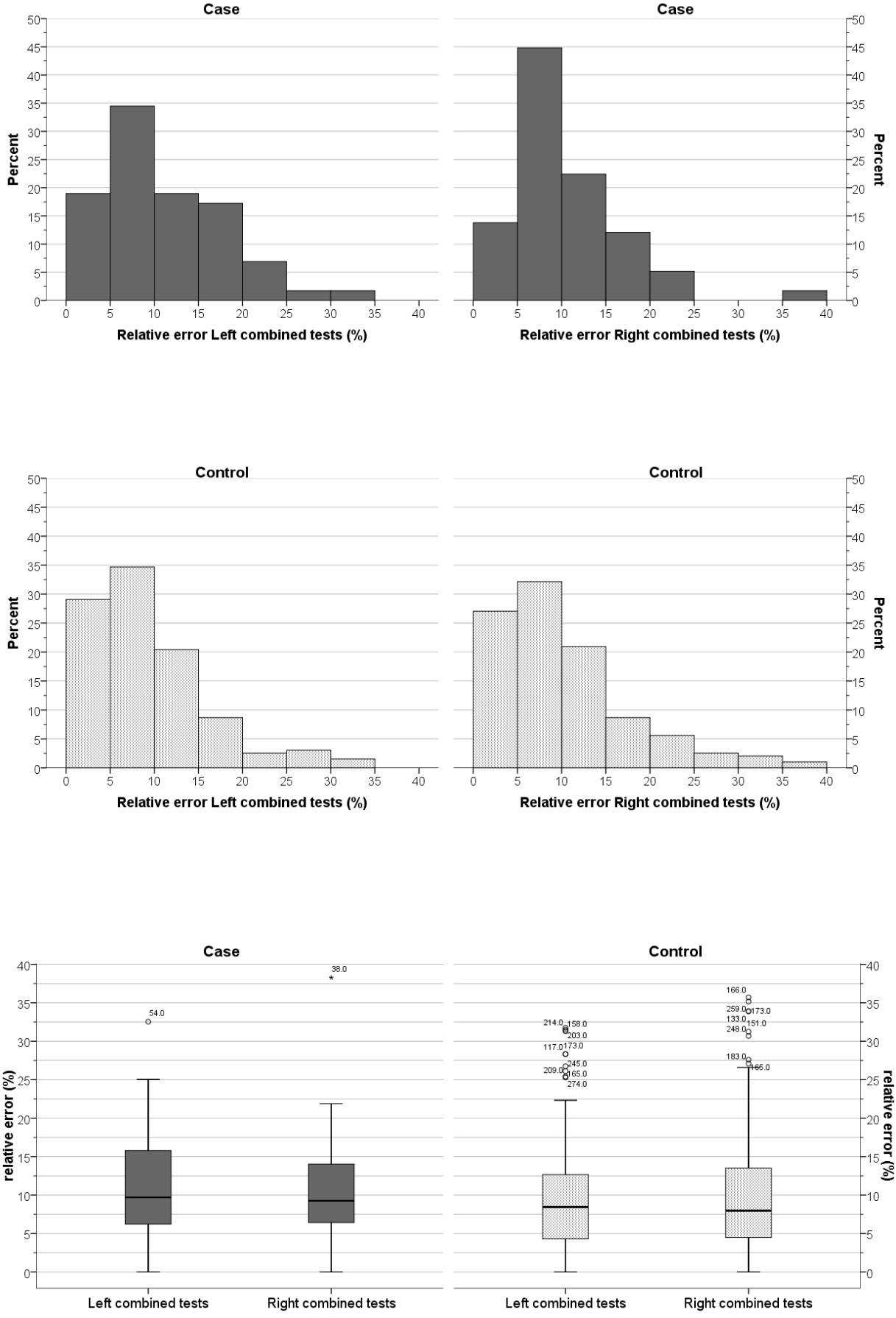


Figure 6.75 Trunk proprioception mean (95% CI) - Left v Right

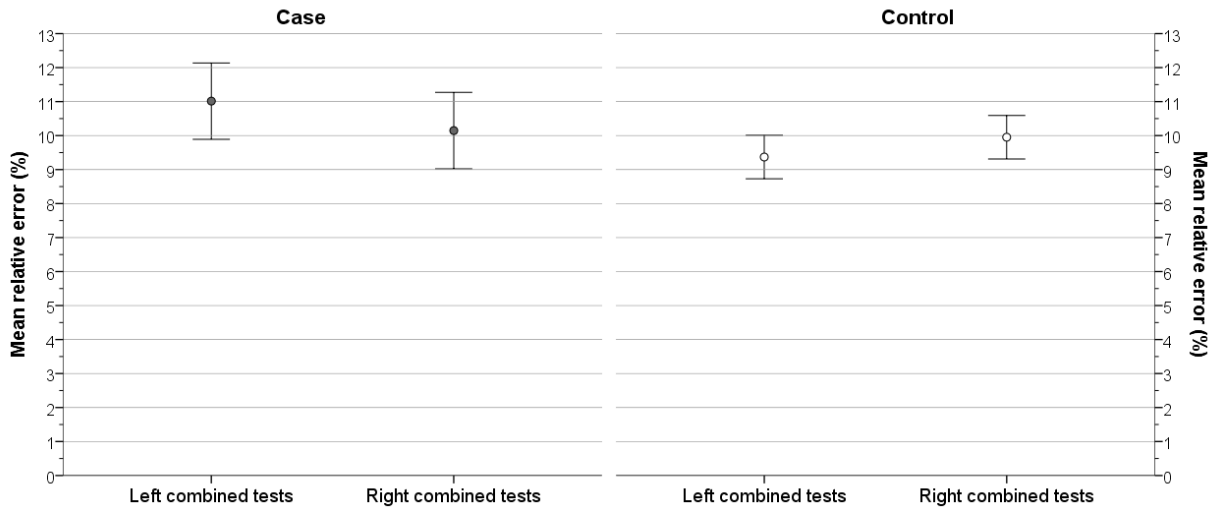


Table 6.87 Proprioception Left v Right - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Left v Right	paired t-test	case	0.87	-1.38, 3.11	0.77	57	0.444	0.13
		control	-0.58	-1.86, 0.70	-0.90	195	0.372	-0.08

6.12.2 Affected v unaffected

Descriptive statistics for Affected and Unaffected side are described in Table 6.88 and Figure 6.76 and Figure 6.77. Statistical analysis of the difference between position matching error of Affected and Unaffected sides within each group was conducted with a paired-samples t-test (Table 6.89).

For cases, on average, there was little difference in position matching ability between tests conducted to the affected or unaffected side (mean $AE_{adjusted}$ = 10.89% and 10.46% respectively) and this difference was not statistically significant (mean difference = 0.43; 95% CI -1.86, 2.73; t = 0.38; DF = 56; p = 0.71; *d* = 0.06).

Similarly for controls, on average there was little difference between tests performed on the affected or unaffected side (mean $AE_{adjusted}$ = 9.57% and 9.60% respectively) and this difference was also not statistically significant (mean difference = -0.03; 95% CI -1.32, 1.26; t = -0.04; DF = 192; p = 0.97; *d* = -0.004).

Table 6.88 Trunk proprioception descriptive statistics - Affected v Unaffected side

	side	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Case (n=57)	A	10.89	6.40	0.85	9.19, 12.59	10.00	6.30, 15.22	0	32.54	1
	U	10.46	6.82	0.90	8.65, 12.27	9.37	6.39, 13.58	0	38.28	
Control (n=193)	A	9.57	7.03	0.51	8.57, 10.57	8.10	4.65, 13.61	0	33.93	4
	U	9.60	6.89	0.50	8.62, 10.58	8.65	4.30, 12.89	0	35.70	

Figure 6.76 Trunk proprioception histograms & boxplots - Affected v Unaffected

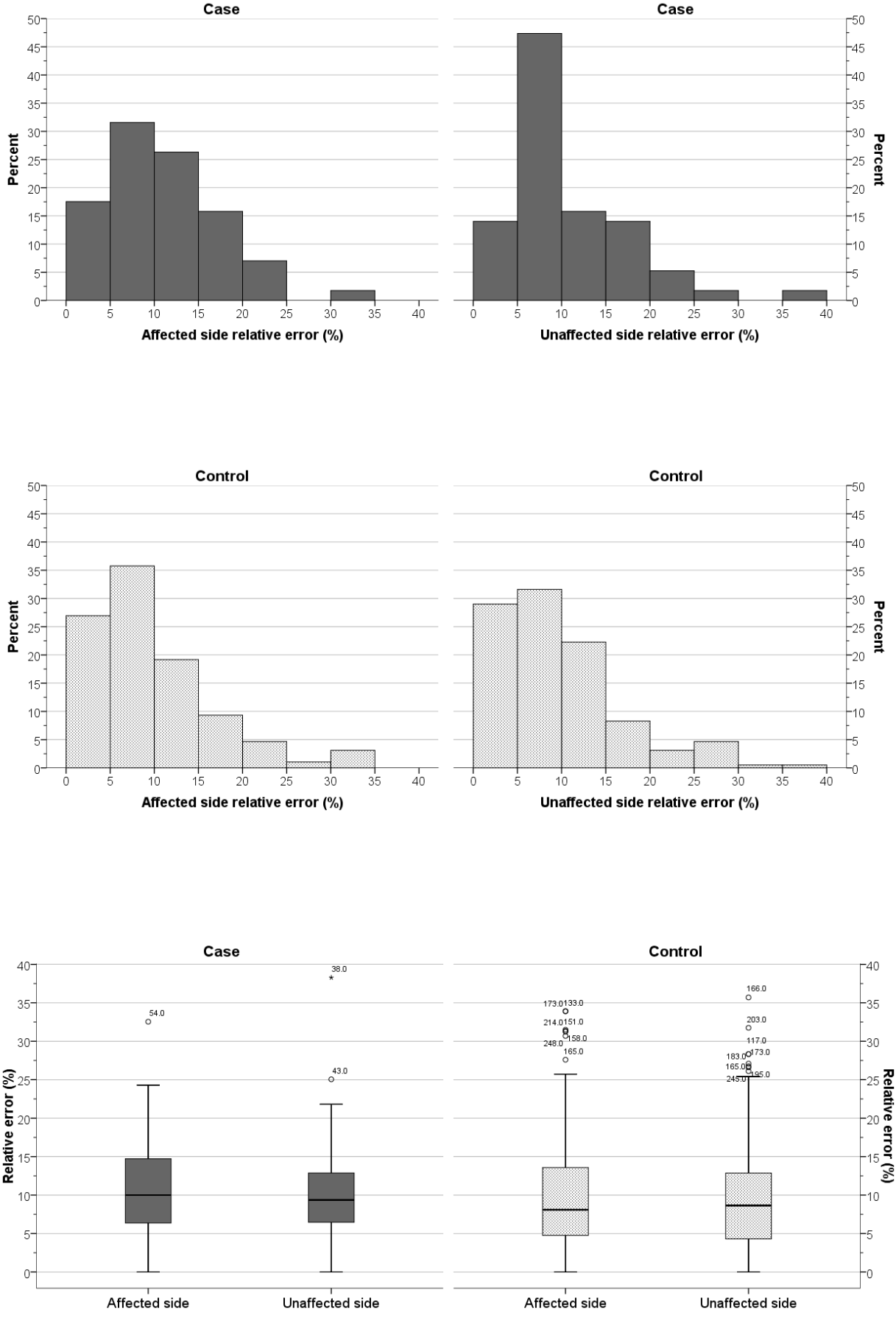


Figure 6.77 Trunk proprioception mean (95% CI) - Affected v Unaffected side mean (95% CI)

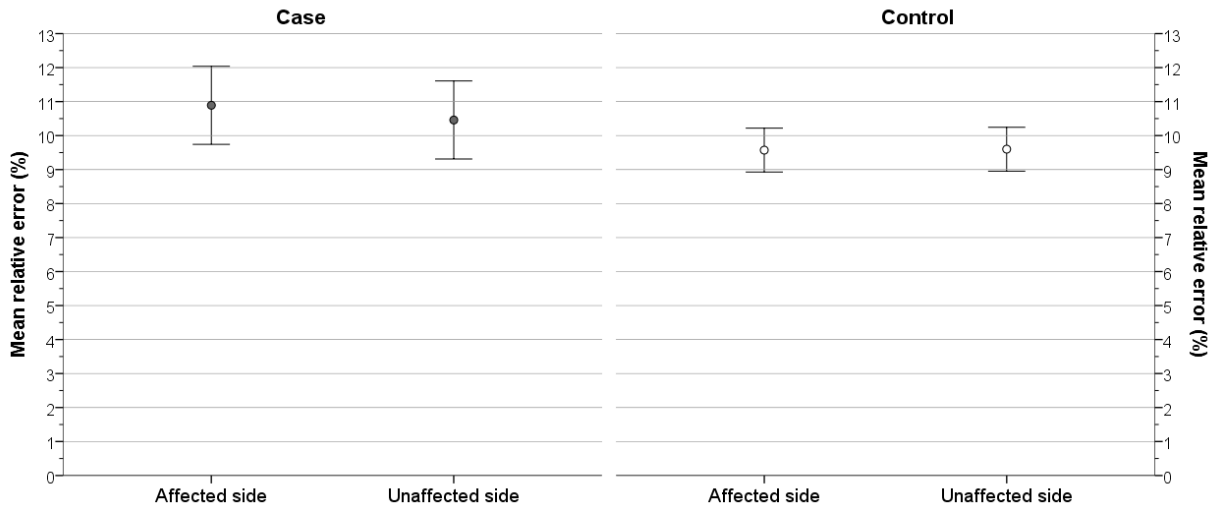


Table 6.89 Proprioception Affected v Unaffected side - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Affected v unaffected	paired t-test	case	0.43	-1.86, 2.73	0.38	56	0.707	0.06
		control	-0.03	-1.32, 1.26	-0.04	192	0.966	-0.004

6.12.3 Case v control

As the differences in position matching error within groups (left v right, affected v unaffected sides) was small and not statistically significant, trials were combined to form one Case and one Control variable allowing for a direct comparison between the two groups.

The distribution of both groups was consistent with a normal distribution (Table 6.90 and Figure 6.78).

On average, the mean difference in position matching ability between case and control participants was small (mean $AE_{adjusted}$ = 10.58% and 9.66% respectively) and this difference was not statistically significant (difference in means = 0.92%; 95% CI -0.65, 2.49; t = 1.16; df = 252; p = 0.25; *d* = 0.17) suggesting no difference between control and case participants (Table 6.91).

A point-biserial correlation was run to determine the relationship between proprioception and group type. Group type was not significantly related to position matching error (r_{pb} = 0.073; 95% BCa CI -0.48, 0.186; p=0.249) and shared only 0.5% of the variability in position matching error (r_{pb}^2=0.005) (Table 6.92).

Table 6.90 Trunk proprioception descriptive statistics - Case v Control

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Case (n=58)	10.58	5.00	0.66	9.26, 11.90	10.01	7.32, 14.01	0	26.26	0
Control (n=196)	9.66	5.42	0.39	8.90, 10.42	8.75	5.85, 12.60	0	31.13	1 (0.5)

Figure 6.78 Trunk proprioception histograms & boxplots - Case v Control

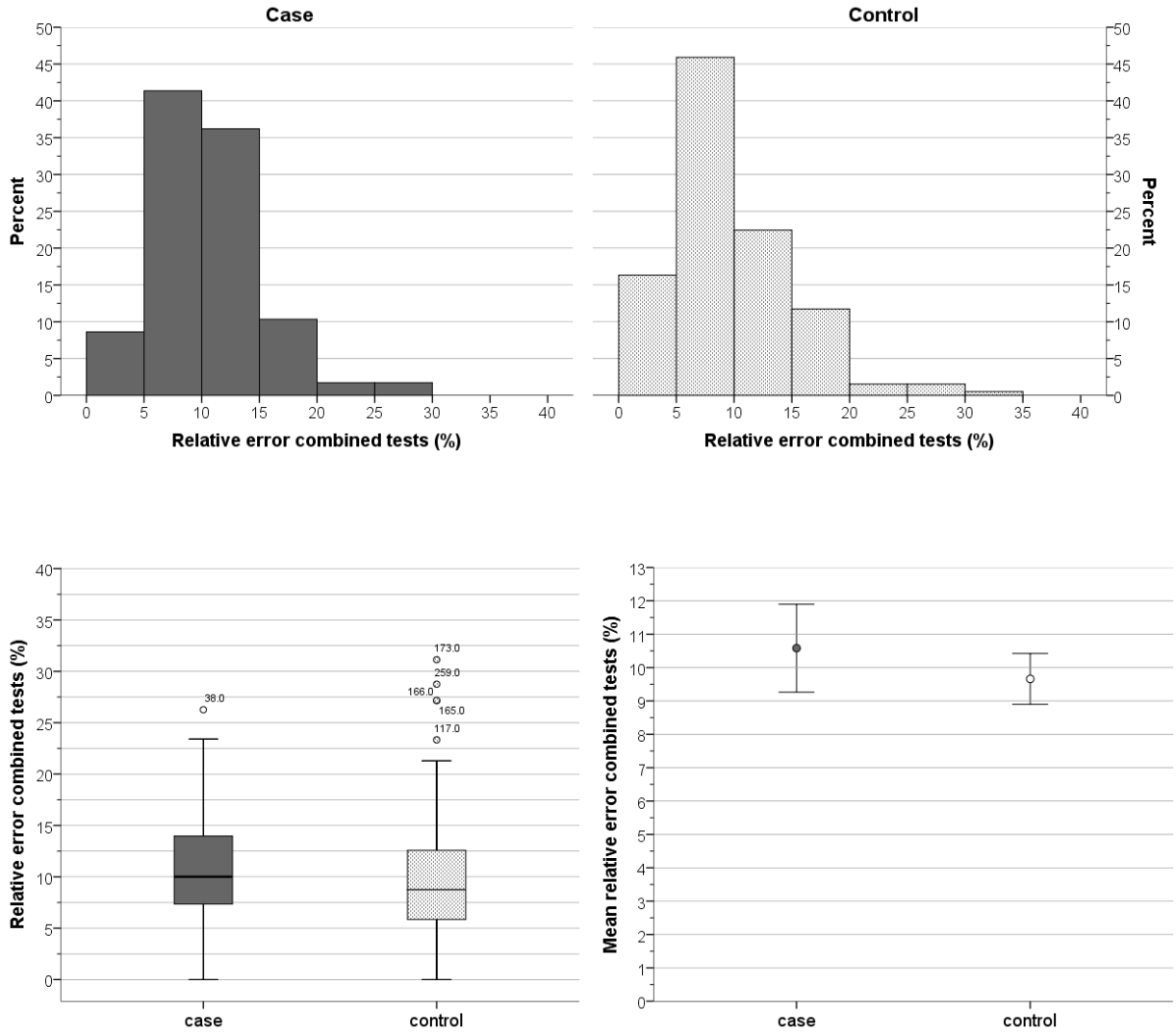


Table 6.91 Trunk proprioception Case v Control - statistical l analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	-	0.92	-0.65, 2.49	1.16	252	0.249	0.17

Table 6.92 Correlation between group type and proprioception

analysis	test	outcome variable	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	position matching error	0.073	-0.48, 0.186	0.005	0.249

6.13 Dynamic standing balance

6.13.1 Left v right

Dynamic standing balance was tested 3 times for both left and right lower limbs. Trials were then averaged to form a single Right-side and Left-side variable for each group.

A number of extreme scores amongst cases whose balance times were very long relative to the rest of their cohort were apparent on examining the data. Investigation revealed that these belonged to two participants in particular (Table 6.93). Participant 1 had very long balance times for all trials apart from the second trial on the right leg. Participant 28 had long balance times for the second and third trials on both left and right legs. In these instances, their balance was between 2.4 to 10 times greater than those of the participant recording the next longest time suggesting either far greater balance ability than the norm or an error in either the timing or recording of the tests. This had the effect of increasing the mean times and the variability for the corresponding trials. Therefore, the balance times for these participants that were more than twice the next longest time were classified as outliers and excluded from further analysis.

Table 6.93 Dynamic standing balance - extreme scores

Participant	sex	age, yrs	Cobb angle primary curve, °	Balance times (secs)					
				R1	R2	R3	L1	L2	L3
1	F	15.58	35	34*	12	46*	100*	48*	126*
28	M	14.75	NA	4	76*	60*	10	44*	60*
next highest time				14	11	8	10	13	15

* balance times more than 2x next highest value

Descriptive statistics and distributions are provided in Table 6.94 and Figure 6.79 and Figure 6.80.

For cases, on average, there was very little difference in balance time between the left and right legs (mean = 3.11 and 3.08 seconds respectively) and this difference was not statistically

significant (mean difference = 0.036 seconds; 95% CI -0.42, 0.49; t = 0.157; DF = 55; p = 0.88; *d* = 0.02) (Table 6.95).

Similarly for controls, on average there was little difference between the left and right legs (mean = 3.67 and 3.75 seconds respectively) and this difference was not statistically significant (mean difference = -0.076 seconds; 95% CI -0.40, 0.25; t = -0.464; DF = 196; p = 0.64; *d* = -0.03).

Table 6.94 Dynamic standing balance descriptive statistics - Left v Right (sec)

	side*	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=56)	L	3.11	1.71	0.23	2.66, 3.57	2.67	2, 3.9	1.00	10.00	2
	R	3.08	1.60	0.21	2.65, 3.51	2.83	1.8, 4	1.00	9.00	2
control (n=197)	L	3.67	2.47	0.18	3.32, 4.02	3.00	2.3, 4	1.00	18.67	0
	R	3.75	2.57	0.18	3.39, 4.11	3.00	2, 4. 7	1.00	16.67	0

*L = left; R = right

Table 6.95 Dynamic standing balance Left v Right - statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Left v Right	paired t-test	case	0.04	-0.42, 0.49	0.16	55	0.88	0.02
		control	-0.08	-0.4, 0.25	-0.46	196	0.64	-0.03

Figure 6.79 Dynamic standing balance histograms & boxplots - Left v Right

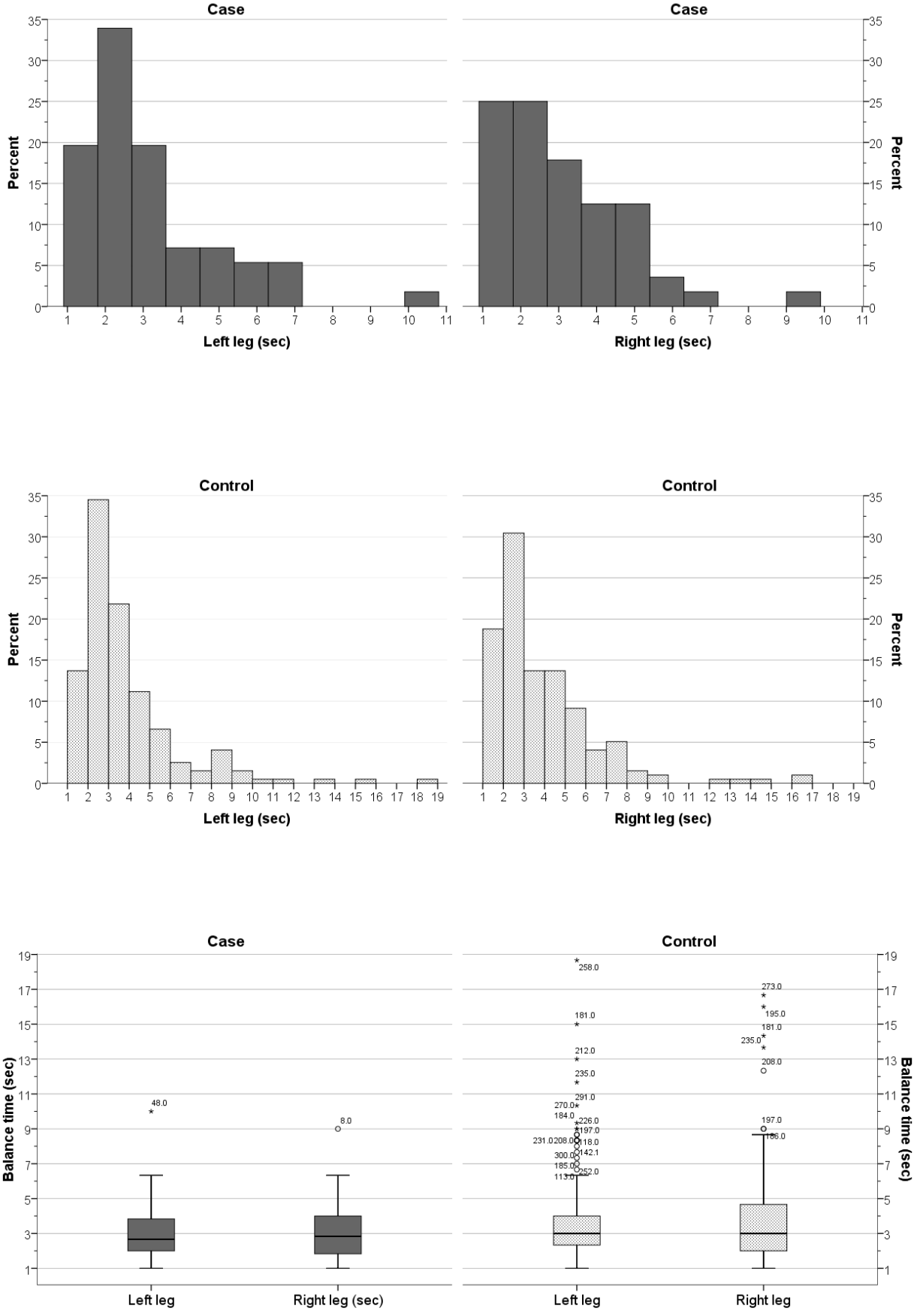
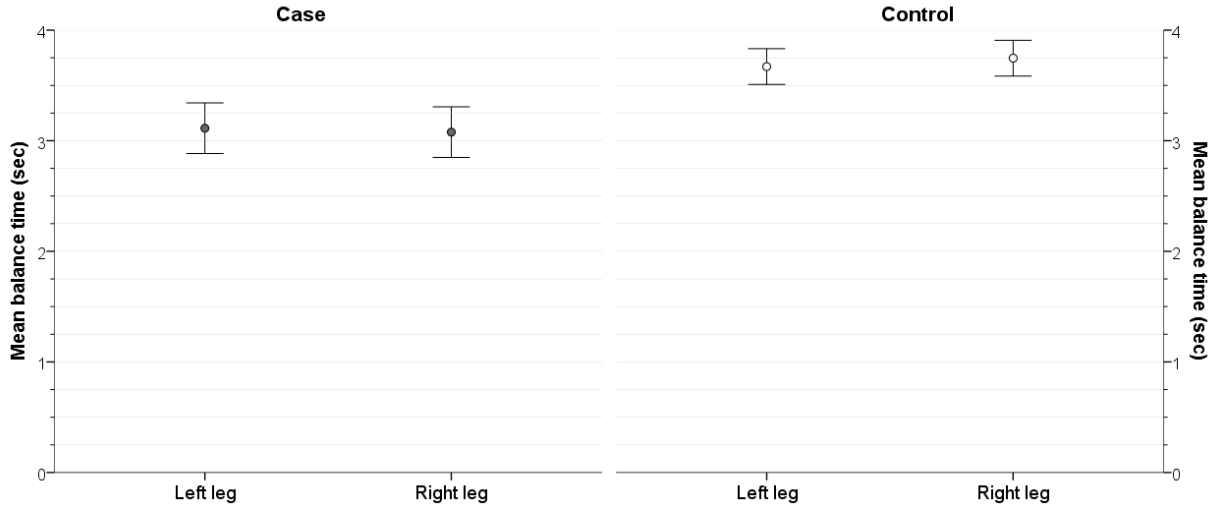


Figure 6.80 Dynamic standing balance mean (95% CI) - Left v Right balance time



6.13.2 Affected v unaffected side

The 6 trials for each side were combined to form an overall Affected-side and Unaffected-side corresponding to the direction of the curve. As was the case with previous analyses, there were a number of extreme scores amongst the cases which all came from the same participant (Table 6.96). They were therefore classified as an outlier and excluded from subsequent analysis (note that x-ray information was not available for a further case participant, therefore it was not possible to categorise the affected or unaffected side for this case, nor their three matching controls).

Table 6.96 Extreme scores

TNO	Trial					
	A1	A2	A3	U1	U2	U3
1	100*	48*	126*	34*	12	46*
next highest time	14	12	8	10	11	15

* more than 2 x next highest score; A1 = Affected-side trial 1 etc; U1 = Unaffected-side trial 1 etc

Descriptive statistics and characteristics of the remaining participants are presented in

Table 6.97 and Figure 6.81and Figure 6.82.

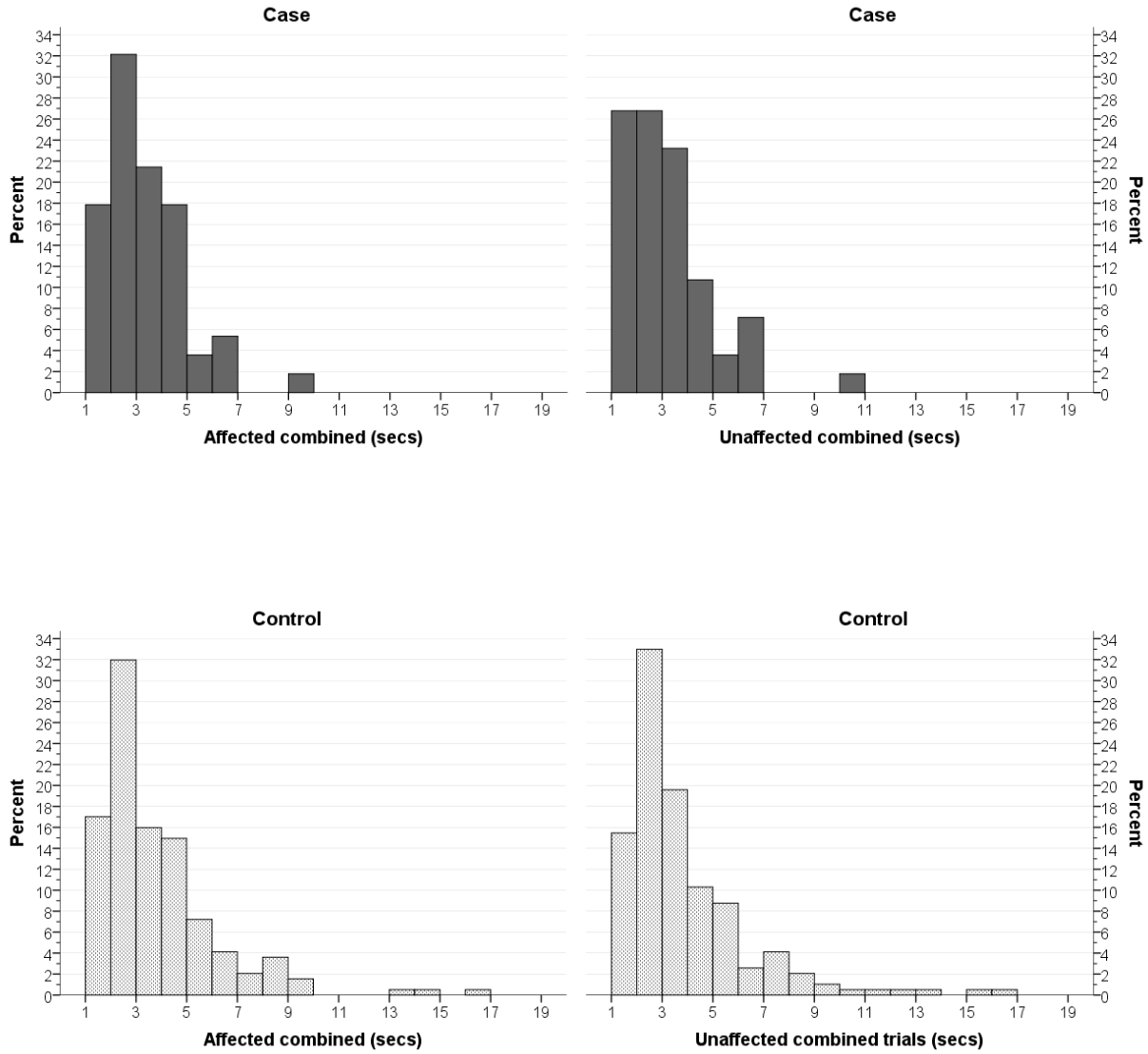
For cases, on average, there was very little difference in balance time between the affected and unaffected sides (mean = 3.17 and 3.02 seconds respectively) and this difference was not statistically significant (mean difference = 0.15 seconds; 95% CI -0.30, 0.61; t = 0.681; DF = 55; p = 0.496; *d* = 0.09) (Table 6.98).

Similarly for controls, on average there was little difference between the affected and unaffected sides (mean = 3.66 and 3.69 seconds respectively) and this difference was not statistically significant (mean difference = -0.04 seconds; 95% CI -0.35, 0.27; t = -0.23; DF = 193; p = 0.82; *d* = -0.01).

Table 6.97 Dynamic standing balance descriptive statistics - Affected v unaffected side

	side	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
case (n=56)	A	3.17	1.58	0.21	2.75, 3.60	2.83	2, 4.33	1.00	9.00	2
	U	3.02	1.73	0.23	2.56, 3.48	2.67	1.67, 3.58	1.00	10.00	2
control (n=194)	A	3.66	2.35	0.17	3.32, 3.99	3.00	2, 4.33	1.00	16.67	3
	U	3.69	2.46	0.18	0.33, 4.04	3.00	2.33, 4.42	1.00	16.00	3

Figure 6.81 Dynamic standing balance histograms & boxplots - Affected v unaffected side



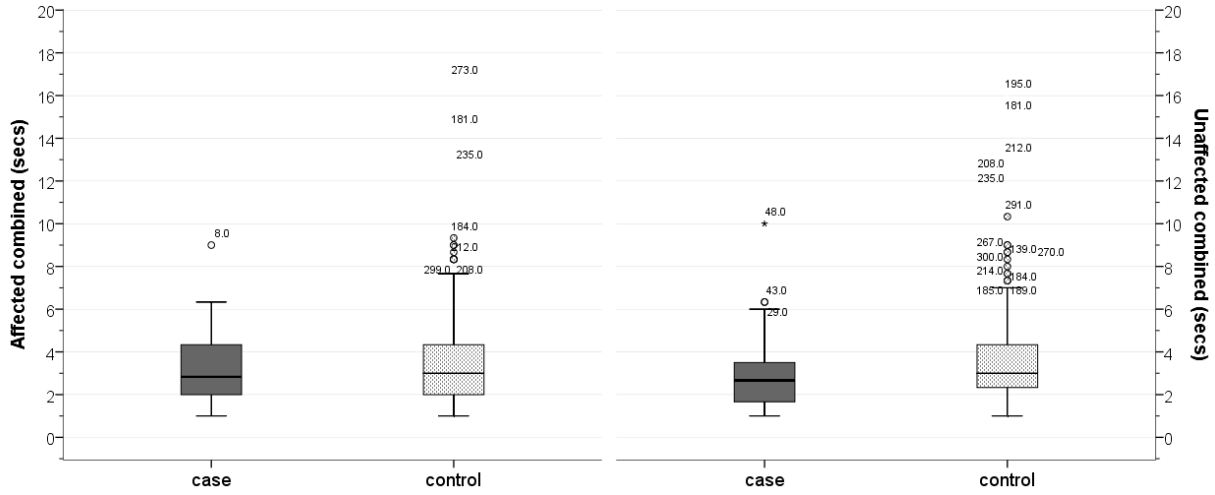


Figure 6.82 Dynamic standing balance means (95% CI) - Affected v unaffected side

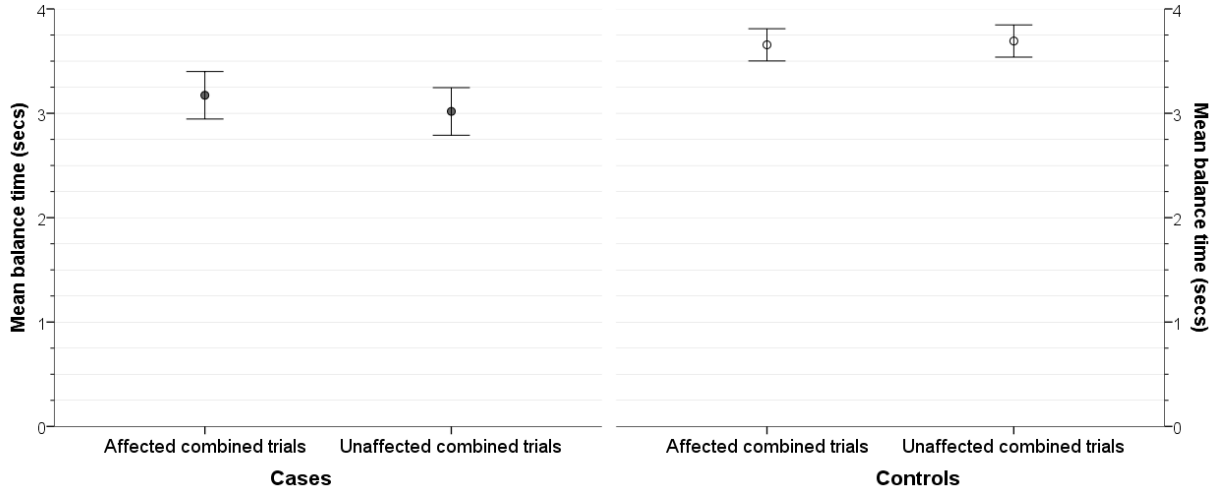


Table 6.98 Dynamic standing balance Affected v Unaffected side - statistical analysis

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
Affected v unaffected	paired t-test	case	0.15	-0.30, 0.61	0.68	55	0.50	0.09
		control	-0.04	-0.35, 0.27	-0.23	193	0.82	-0.01

6.13.3 Case v control

As little difference was found related to curve direction or between left and right balance times within groups, all trials were combined into one variable to allow for a direct comparison between case and control participants using all their respective data. These are summarised in Figure 6.83 and Table 6.99.

Data for both groups, particularly controls, was positively skewed with scores again clustered around the lower times. Average times were therefore correspondingly low with small differences in mean and median scores between groups.

Due to the lack of normality and homogeneity of variance displayed by the data, a $\log_{10}$ transformation was applied to both groups (Figure 6.84 and Table 6.99).

On average, control participants were able to maintain balance longer than cases although the difference between groups was small (untransformed mean = 3.10 and 3.71 seconds cases and controls respectively). Transformation of the data resulted in means of 0.45 and 0.51 $\log_{10}$-seconds for cases and controls respectively (geometric means of 2.81 and 3.24 seconds) with a difference of 0.063. The corresponding geometric mean ratio was 1.15 (95% CI 1.00 to 1.34), i.e. on average, controls balance times were 1.15 times the balance times of cases. The confidence interval for the ratio includes 1 which implies no difference between the geometric means.

Statistical analysis was performed using an independent-samples t-test on the transformed data (Table 6.100). The difference between groups was not statistically significant (95% CI -0.125, 0.001; t = 1.949 equal variances assumed; DF = 251; p = 0.052; *d* = 0.29).

A point-biserial correlation was run to determine the relationship between balance and group type. Group type was not significantly related to balance time (r_{pb} = 0.093; 95% BCa CI -0.147, 0.189; p=0.140) and shared only 0.9% of the variability in dynamic standing balance time (r_{pb}^2=0.009) (Table 6.101).

Table 6.99 Dynamic standing balance descriptive statistics- Case v control (untransformed and log_{10})

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)	missing %
case (n=56)	3.10	1.42	0.19	2.71, 3.48	2.83	1.88, 3.95	1.00	7.33	2	3.4
log_{10}	0.45	0.20	0.03	0.40, 0.50	0.45	0.27, 0.60	0.00	0.87	2	3.4
control (n=197)	3.71	2.24	0.16	3.39, 4.02	3.00	2.33, 4.5	1.33	14.67	0	0
log_{10}	0.51	0.22	0.02	0.48, 0.54	0.48	0.37, 0.65	0.12	1.17	0	0

Figure 6.83 Dynamic standing balance histograms, boxplots & means (95% CI) - Case v control

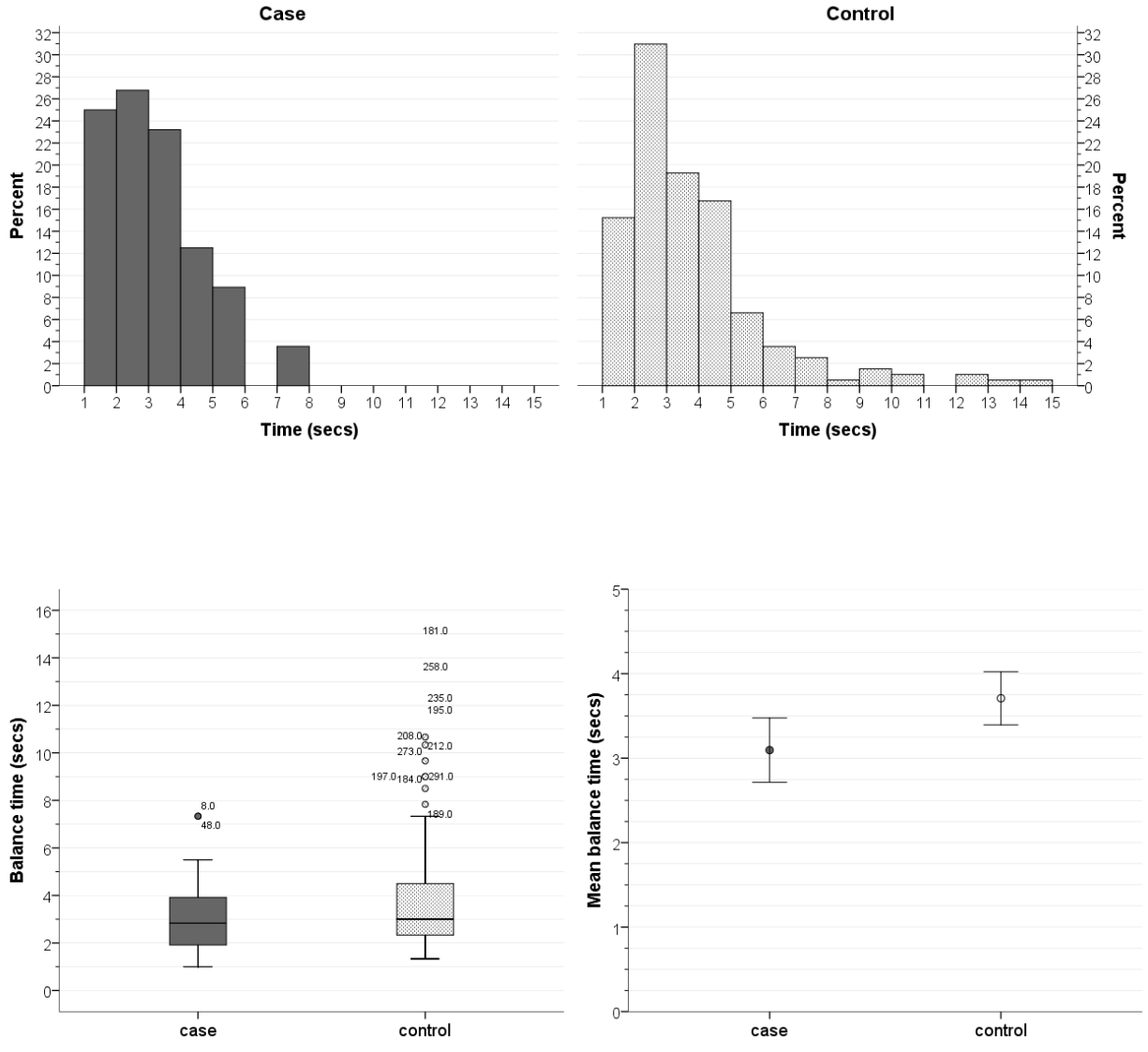


Figure 6.84 Dynamic standing balance histograms, boxplots & means- Case v control Log10 transformation

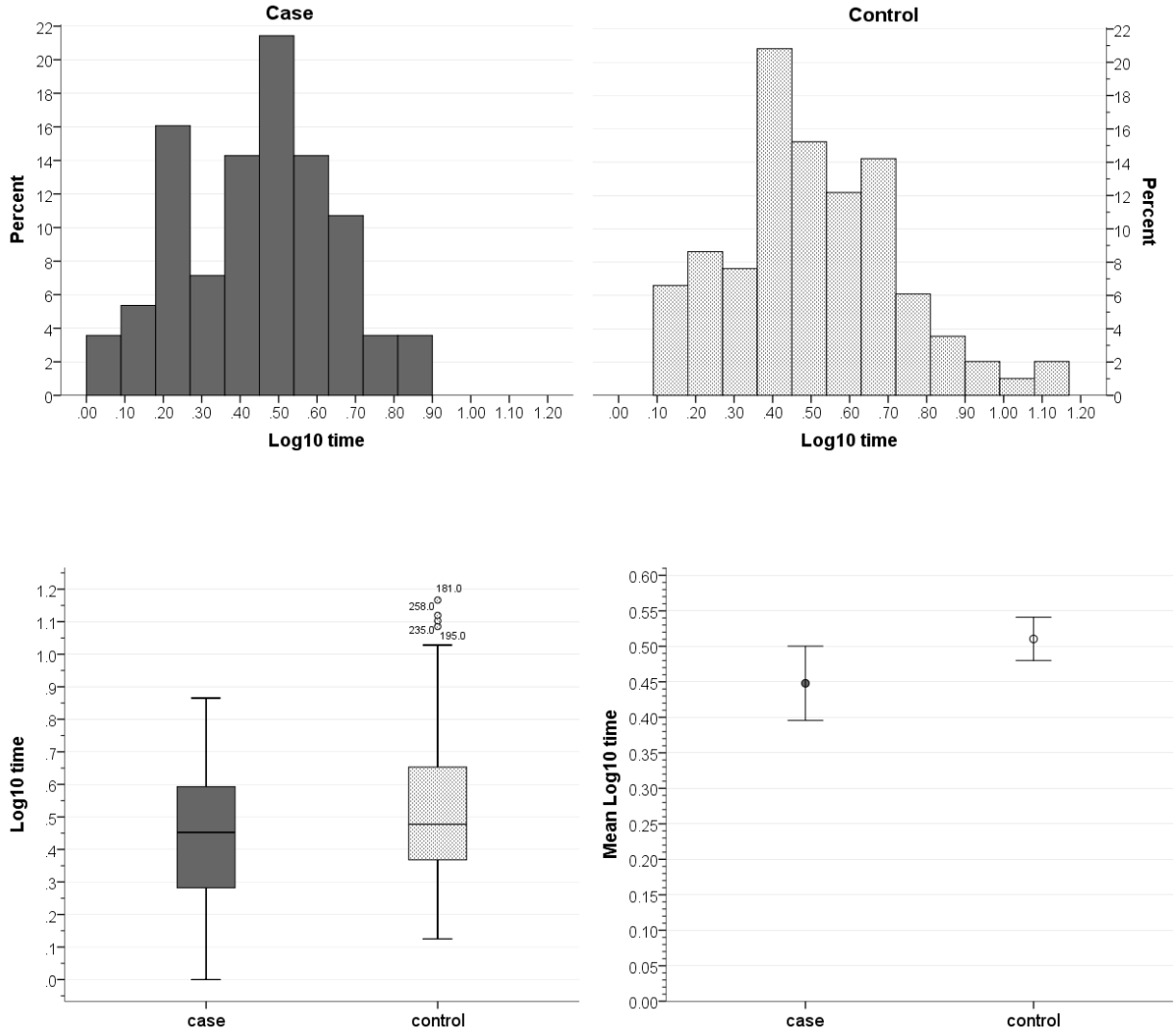


Table 6.100 Dynamic standing balance Case v Control- statistical analyses

analysis	test	group	diff means	95% CI of diff. means	t-statistic	df	p-value	Cohen's *d*
case v control	independent t-test	log_{10} values	-0.06	-0.13, 0.001	-1.95	251	0.052	-0.29

Table 6.101 Correlation between group type and balance

analysis	test	outcome variable	r_{pb}	95% BCa CI	r_{pb}^2	p-value
case v control	bi-serial correlation	balance time	0.093	-0.147, 0.189	0.009	0.140

6.14 Summary

6.14.1 Demographics

Overall, the demographic data from both groups suggested that the recruitment and matching process was successful in terms of creating groups of similar characteristics. Participants from both groups spanned the eligible age range (10-17yrs) although there was a slight bias towards the older age groups. Figures for ethnicity were comparable for both groups and reflect the general population of England [7]. The ratio of female:male participants was equal for both groups and was in line with previously reported figures for AIS (see Chapter 1.3.1).

A small difference was noted between groups in terms of self-reported puberty status, with a greater proportion of case participants stating they had reached puberty at the time of inclusion into the study. A greater proportion of case participants also reported other family members with scoliosis which is not an unexpected outcome as there is known to be some genetic component to the aetiology of AIS (see section 1.3.4).

Control participants reported higher estimates of weekly family income than case participants. It is unclear why this occurred although a sizeable proportion of control participants were recruited from private fee-paying schools. No information was collected regarding school-type from case participants so this cannot be evaluated in greater detail. Estimates of family income were based on postcode estimates from the Office of National Statistics. Attempts were made initially to collect self-reported data of parental income from participants but this was poorly completed, especially by control participants.

Apart from these differences, the groups appeared to be similar with regard to demographic characteristics. The small differences between groups on some parameters are unlikely to have a major impact on the results.

6.14.2 Spinal characteristics - cases

The case participants were representative of the general AIS population in terms of spinal deformity. The majority of curves were in the thoracic region and convex to the right, consistent with descriptions from previous epidemiological studies [8]. The degree of deformity, as defined by the Cobb angle, covered the spectrum from mild to severe scoliosis (14 to 50^{o}), with the majority of cases falling into the moderate AIS category (IQR 27-41^{o}).

6.14.3 Perceived trunk symmetry

Perceived trunk symmetry was measured using the SAQ. There are no previously published normative values for the SAQ for people without AIS. Control participant scores for all scales were on average lower (i.e. better) than case participants. Scores for case participants were consistent with previous reports of people with Cobb angles of a similar range or larger than the participants in this study [9-11].

Large correlation coefficients between SAQ scales and group were observed indicating that group type was strongly associated with perceived trunk symmetry. This was confirmed by non-parametric significance testing. Large statistically significant differences between case and control groups were recorded with case participants' scores approximately double (i.e. worse) that of controls for both the appearance and expectations subscales, as well as the total score. This suggests that, at least for the participants in this study, people with AIS are aware of the changes in their spine and perceive the symmetry of their trunk to be markedly different from normal.

6.14.4 Body Awareness

Kinaesthetic and proprioceptive awareness was measured by the KPAQ. Case and control participants recorded similar scores with cases reporting slightly lower (i.e. worse) scores on average.

Very weak correlations between KPAQ and group were observed indicating that group type was only weakly associated with self-reported body awareness. These results were confirmed by non-parametric significance testing. A small, statistically significant difference between case and control groups was recorded (difference in medians = 2.5), suggesting that cases were worse than control participants in terms of kinaesthetic and proprioceptive awareness. However, the effect size was very modest and it is uncertain whether this difference is sufficient to be of clinical significance.

6.14.5 Health related quality of life (HRQoL)

Two measures were used to evaluate HRQoL in this study: a condition-specific (SRS-22r) and a generic (EQ5D) instrument.

6.14.5.1 Generic

Overall, very few participants reported severe or extreme problems in any of the 5 domains evaluated by the EQ5D. For this reason, responses were collapsed down into categories of problems and no problems.

Normative values for the EQ5D-3L published by the EuroQol Group do not cover children or adolescents. The closest age group for which data are available is for 18-24 yr olds [12]. In this age group, the proportions of people reporting problems with the EQ5D-3L domains in England (n=1259, 572M: 687F), along with the mean health state visual analogue scale (VAS) score, are reported in Table 6.102. The results of the case control study are included for comparison.

Table 6.102 Proportion of people reporting problems (%) and mean VAS score

	mobility	self care	usual activities	pain / discomfort	anxiety / depression	health state VAS
EuroQol England 18-24yrs	4.0	0.8	4.4	16.0	15.6	86.5
Cases	17.5	1.8	21.1	66.7	26.3	77.65
Controls	2.0	1.0	3.0	16.2	16.8	88.65

The proportion of control participants reporting problems in the case control study were similar to those described for 18-24 yr-olds in England. In contrast, the proportion of case participants reporting problems were approximately 4 to 5 times higher than the published normative values and control participants for mobility, usual activities and pain domains. The proportions with anxiety problems were also greater for case participants though to a lesser extent.

The differences between case and control participants were statistically significant for the mobility, usual activity and pain domains. They also reflect the large odds ratios recorded for these domains although wide 95% confidence intervals indicate the large variability.

A statistically significant difference between case and control participants was also observed for the health state VAS. Previous reports in the literature across a range of health conditions

have proposed a MCID of between 6.5 to 11 points for this measure [13-15]. The 7 point difference observed between group medians suggests that the difference is at or just below what would be necessary for a clinically important difference to be observed.

Overall, these results suggest that people with AIS experience lower health-related quality of life than people of a similar age, as well as young adults. The limited number of possible responses for the 3L version of the EQ5D, compounded by the collapsing of these into binary categories, makes it difficult to evaluate these results in greater detail.

6.14.5.2 Condition specific

Control participants scored towards the upper end on all subscales of the SRS-22r indicating high levels of health-related quality of life. Their scores were generally higher than those previously reported for people of a similar age with no known scoliosis [16].

Case participants generally recorded lower scores in comparison to the control participants, particularly for the pain and self-image scales. The pain and self-image scales were also the only two scales in which cases scored lower than the previously published normative data [16]. Function, mental health and subtotal scores were consistent with those described for people with similar magnitudes of Cobb angle [9, 17-19]. In contrast, the scores for pain and self-image recorded as part of this study were generally worse than people with similar magnitudes of Cobb angle and more in line with previous reports of people with larger levels of spinal deformity [9, 10, 17-21]. The reasons for this remain unclear.

The differences between cases and controls for self-reported pain and self-image were confirmed with statistical testing. No statistically significant difference between groups was reported for mental health. Although statistical analysis of the function scale described a statistically significant difference between groups, there was no difference in median function scores and the effect size was very low

These results indicate that people with AIS report greater pain and have more self-image concerns than their non-scoliotic counterparts. The difference between groups was greater than previously published MCID figures for pain and self-image suggesting that these differences are clinically meaningful [21-23].

6.14.6 Generic function

Generic function was measured using the PODCI. Scores for both case and control participants in this study were consistent with previous reports of people with and without scoliosis respectively [Lerman et al 2002] with case participants generally scoring lower (i.e. worse) than controls for all PODCI scales.

Weak correlations between the various scales and group were observed indicating that group type was only weakly associated with function. The strongest relationships were with pain, global function and happiness with physical condition domains although group type only accounted for a relatively small amount of variability in each of these scales (< 12%).

These results were confirmed by non-parametric significance testing. Large statistically significant differences were reported between group medians for pain and happiness, with smaller differences for global function and sports function. However, effect sizes for all of these were generally modest (<0.30, Pearson's r).

These findings indicate that people with AIS do not suffer any major deficits with regard to generic function except for perhaps pain and possibly happiness with physical condition.

6.14.7 Tactile acuity

Tactile acuity was assessed through TPDT and localisation ability testing.

6.14.7.1 Two point discrimination threshold (TPDT)

Within-group analyses of side-to-side differences were conducted for left v right and affected v unaffected side (affected = curve direction of main curve). No significant differences were reported for cases for these analyses. Differences between mean TPDTs for controls were only slightly larger than for cases but were sufficient to be statistically significant for left v right and affected v unaffected sides. However, the effect size for both was relatively small.

Overall, median TPDTs for case and control participants were consistent with previously reported threshold distances for the lumbar and thoracic spine in healthy adults (see section 3.2.i), although there was substantial variability. Group type and TPDT was only weakly correlated although on average, case participants reported greater TPDTs than control participants which was statistically significant. These results suggest that people with AIS

display less tactile acuity than people without AIS, although the difference was small (i.e. ≤1cm). It is unclear if this difference is clinically significant.

Of interest is the fact that TPDT was unable to be calculated for one or both sides of the spine in a large proportion of case participants (19% v 1% cases and control respectively). In these participants, the lack of response consistency and the failure to identify one-point catch trials resulted in their testing declared void. It is unclear why this occurred in cases to a greater extent than control participants.

6.14.7.2 Localisation

Within-group analyses of side-to-side differences were conducted for left v right and affected v unaffected side. The differences in the number of correct responses for both case and control groups were very small (i.e. less than 1) and this was not statistically significant indicating no differences in ability to localise the site of stimulation between sides.

Overall, localisation ability (as defined by the number of correct responses) for case and control participants were much lower than those reported by Wand et al [24], where distance between testing sites was large, but very similar to the study by Harvie et al [25], whose study of localisation accuracy in the neck used distances between sites similar to those in this case control study. The high accuracy figures for the ability to at least locate the correct side of stimulation are more reflective of the testing protocol used by Wand et al [24], hence the similarity of results for this analysis.

As with TPDT, only weak correlations were observed between group type and localisation accuracy. Significance testing of the difference between group means revealed that on average, control participants reported more correct responses than case participants. Although statistically significant, control participants were only slightly more accurate in locating the correct side than cases, reflecting the fact that both groups scored highly on this task. These results suggest that people with AIS display less localisation accuracy than people without AIS, although the difference was small. It is unclear if these differences are clinically significant.

6.14.8 Left/right judgement

Testing of left/right judgement ability involved evaluations of accuracy and reaction time for both images of the hand and the trunk.

6.14.8.1 Accuracy

Within-group analyses of side-to-side differences were conducted for left v right and affected v unaffected side. For controls, the difference in accuracy between sides was small and not statistically significant when viewing images of the hand and trunk. For case participants, a small statistically significant difference was observed between left and right sides for judgement accuracy of hand and trunk images. However, these differences were small (2-3%), with corresponding small effect sizes, and were not seen in the analyses taking into account curve direction (affected v unaffected).

Overall, the left/right judgement accuracy for both groups was consistent with previously reported figures for hand and trunk images (see section 3.2.1). Correlations between group type and judgement accuracy were very low and this was reflected in the lack of a statistically significant difference between case and control participants on average.

6.14.8.2 Reaction time

Within-group analyses of side-to-side differences in reaction time for correct responses were conducted for left v right and affected v unaffected side. In general, there were no significant differences between sides for either case or control groups when viewing images of the hand or trunk.

Overall, the time to make a correct decision for both groups was consistent with previously reported figures for hand and trunk images (see section 3.2.1), although cases tended be slower. This difference was not statistically significant when viewing images of the trunk. In contrast, the small difference in reaction times when viewing images of the hand (difference in means = 0.36 seconds, 0.04-0.68 95% CI) was statistically significant despite only weak correlation between group type and reaction time.

In summary, the results indicate that on average there is no difference in accuracy of left/right judgement between case and control participants. There also appears to be no difference between groups in the time taken to make those judgements, at least for images of the trunk.

Of interest, the reaction times when making correct left/right judgments were slower when viewing images of the hand than for the back. In testing of the hands, participants were requested to distinguish whether the image was of a left or right hand, whereas, for images of

the trunk, participants were required to judge the direction of movement. Therefore, whether the faster times when judging trunk images represents a greater ability to judge left from right in the trunk, or a reflection of the slight difference in task between the two sets of images is uncertain.

Also of interest was the difference between reaction times for correct left/right judgements in comparison to incorrect judgements. When viewing images of both the hand and the trunk, the response times for correct responses were faster on average. Within group analyses revealed that these differences were statistically significant for both case and control groups. Previous reports have also highlighted this effect and ascribed it to the extra time and difficulty required to mentally transform the internal body representation to match that of the viewed image [26, 27].

6.14.9 Spatial perception

Spatial perception was evaluated using the line bisection test. A number of within-group analyses were conducted to examine error in midline judgement alongside factors such as hand used, line length, test paper position, and side-to-side differences.

In general, participants from both groups were very accurate in estimating the midpoint of a line .This held true regardless of the different test manipulations including line length, hand used, position of the test paper and curve direction. No statistically significant differences were reported for any of these factors amongst case participants. Small differences were reported between left and right hands and for the test paper position in the control group.

Overall, the % error for both cases and controls was consistent with previously published reports (see section 3.3.1). The difference between the groups was not statistically significant which is consistent with weak correlation between group type and midline error. These results suggest that there is no difference in people with AIS and those without with regard to spatial perception.

The line bisection testing also included evaluation of midline perception error between a standard straight line and one that was drawn within the shape of a torso. Within-group analyses of the difference in error between these two conditions (standard v body line) revealed a statistically significant difference in both case and control groups with lower % error when midline judgements were made with the body line. The mean errors for body lines for

cases and controls equated to distances of 1.67 mm and 1.61 mm respectively. In comparison, when using the standard lines, the mean errors equated to distances of between 4.96 to 6.20 mm for case participants and 4.76 to 5.95 mm for control participants (depending on line length). It is uncertain why this was the case.

6.14.10 Proprioception

Within-group analyses of side-to-side differences were conducted for left v right and affected v unaffected side. No statistically significant differences in position matching error were reported for either cases or controls for these analyses.

Overall, there was less than a 1% difference in position matching error between case and control participants. This difference was not statistically significant. These results, combined with a very weak correlation between group type and position matching error, indicate that there is no difference between people with AIS and those without with regards to trunk proprioceptive ability.

6.14.11 Balance

In general, both case and control participants performed poorly on the dynamic standing balance test, only being able to maintain balance for median times of approximately 2.5-3 seconds. Within-group analyses of side-to-side differences were conducted for left v right and affected v unaffected side. No significant differences in balance time were reported for either cases or controls for these analyses.

Overall, case and control participants had very similar balance times and these were consistent with previously reported values in an adolescent population [28]. On average, there was less than a 1 second difference in balance time between case and control participants and this was not statistically significant. These results, combined with a very weak correlation between group type and balance time, indicate that there is no difference between people with AIS and those without with regards to dynamic standing balance.

6.14.12 Limitations

The most important sources of bias associated with case control study designs include selection bias and measurement (observer) bias [29]. Measures to avoid or reduce these in relation to this study were described in section 5.2.8.

Limitations of case control designs also include an inability to infer causality or determine the temporal sequence of condition and the variable of interest [29]. A discussion of other limitations specific to this study include the following:

6.14.12.1 Prevalent v incident cases

The case participants recruited for this study were not confined to those who had suffered recent onset of AIS, or who had been recently diagnosed. Therefore, the duration of the condition amongst the group varied to some extent and this may have affected the results. Participants with AIS of longer duration, who may have undergone previous treatment, investigations and had longer to adjust to the condition and its potential consequences, may respond differently to questionnaires and physical testing than those diagnosed more recently.

6.14.12.2 Control recruitment

The recruitment of controls from schools was an attempt to minimise the potential for selection bias as described previously. However, the response from schools was, in the main, very poor which resulted in recruitment occurring from all schools that were willing to be involved, rather than being able to randomly select from a list of potential recruitment sources. It is unclear as to how this may have affected the results of this study as no information was collected from case participants as to school type. It is possible that the observed difference in income estimates is a clue to the potential effect of this limitation. However, socioeconomic factors are not known to be a factor in the development of AIS, and case and control participants appeared to be comparable on all other relevant demographic factors.

(iii) Measurement properties

Some of the self-report measures used in this study appeared to be lacking with regard to psychometric properties for use in the participant groups involved.

For example, the PODCI exhibited ceiling effects for most subscales that indicate that it is not suitable for use in healthy adolescents or in those with AIS who do not have any other significant medical condition. The pain, and possibly the happiness with physical condition subscales, were the only ones that did not exhibit this effect. The high scoring of participants in this study is probably a reflection of the fact that the PODCI was originally developed to evaluate children and adolescents who had problems related to bone and muscle conditions

necessitating orthopaedic interventions. It appears that it is not sensitive enough for those without any major health conditions or in adolescents with mild to moderate AIS.

Similar extreme effects were also noted for the EQ5D 3L, SAQ and some subscales of the SRS-22r.

6.14.13 Conclusion

The case control study that was conducted as part of this thesis set out to establish whether adolescents with AIS differ from non-scoliotic adolescents with regard to mechanisms thought to underpin body schema. The results presented in this chapter from both physical testing and self-report questionnaires suggest that no major difference exists in these mechanisms and therefore, calls into question the role of a disrupted body schema in the development of AIS.

Differences have been found in relation to other aspects such as perceived trunk symmetry and health-related quality of life, as well as pain and self-image. Although these were not central to the main research question, they are relevant and important in considering how best to deal with this condition. Further exploration of this area will take place in the overall discussion of this thesis (Chapter 10).

7 Research question 2 - correlational analysis (methods)

This chapter describes the methodology used in the cross-sectional correlation analysis conducted as part of this thesis. A brief overview of the research question the study is addressing is provided initially. The rest of this chapter then focuses specifically on the methodology with the results described in chapter 7.

7.1 Overview

7.1.1 Research question

The research questions that this thesis is seeking to answer are listed below (Table 7.1). The cross-sectional correlation analysis is concerned with answering the second of these questions.

Table 7.1 Research question - correlation study

	Research questions
1	do adolescents with AIS (cases) differ from non-scoliotic adolescents (controls) with regard to mechanisms that are thought to underpin body schema?
2	**in adolescents with AIS, is there any relationship between the mechanisms thought to underpin body schema and the magnitude of spinal deformity?**
3	is there any relationship between changes in body schema and progression of the spinal deformity in AIS over time?

7.1.2 Hypothesis tested

The hypothesis derived from the above question is that:

> H_1: *in adolescents with AIS, a relationship exists between mechanisms that are thought to underpin body schema and measures of spinal deformity.*

The null hypothesis (H_o) is that there is no relationship between underlying mechanisms of body schema and measures of spinal deformity.

7.2 Methods

7.2.1 Study design

To test the proposed hypothesis, a cross-sectional analysis evaluating measures of body schema and spinal deformity in AIS patients was conducted. Data obtained from participants with AIS as part of the case control study described in chapters 4 and 5 was used for this study.

The setting, methods of participant recruitment (including inclusion and exclusion criteria), potential biases and ethics have been described previously in sections 5.2.2, 5.2.3, 5.2.8 and 5.2.10 respectively.

7.2.2 Variables

Information collected from participants with AIS is described in sections 5.2.4 to 5.2.7 and listed in Tables 5.2 and 5.3. These include all the self-report and physical measures from which data was obtained for this correlation study.

7.2.2.1 Radiological measures

In the case control study, the x-ray information was used to characterise the AIS participants to evaluate how typical they were of the general AIS population (Table 5.2). In this correlation study, the x-ray information will be analysed in order to evaluate the study hypotheses. A complete list of measures collected from radiological examination are listed in Table 7.2.

Table 7.2 X-ray variables

Variable	data type
Curve type	categorical (single, double, triple)
Curve direction*	categorical (left, right)
Curve location*	categorical (thoracic, thoracolumbar, lumbar, unknown)
Cobb angle*	continuous (degrees)
Coronal balance	continuous (mm)
Sagittal balance	continuous (mm)
Risser sign	categorical (0-5)

* of primary curve

7.2.2.2 Surface topography

As well as information from radiological examination, a subset of participants with AIS also underwent surface topography measurements of the back, which is another method of evaluating spinal deformity (see section 1.1). The Integrated Shape Imaging System (ISIS-2) produces contour surface maps of the posterior trunk to highlight asymmetry and cosmetic changes in body shape that occur as a result of the changes in the scoliotic spine [1]. A number of different parameters are calculated in order to characterise the shape of the posterior trunk (Table 7.3).

Table 7.3 ISIS2 variables

Variable	data type
Lateral asymmetry*	continuous (degrees)
Volumetric asymmetry*	continuous (degrees)
Coronal balance	continuous (mm)
Sagittal balance	continuous (mm)
Transverse rotation	continuous (degrees)
Flexion/extension angle	continuous (degrees)

* corresponding to primary curve direction

The relevant details are described in detail in Appendix 19 but briefly,

- Lateral asymmetry attempts to capture surface changes in the coronal or frontal plane caused by underlying deviation of the spine. The derived value corresponds to the Cobb angle from radiological examination.
- Volumetric asymmetry refers to the differences in surface area between the left and right side of the spine. Due to the contour-like maps that are produced, a 3-D image can be drawn and overall volume differences calculated.
- Coronal and sagittal balance are similar to the equivalent measures from x-rays which capture the distance between plumb lines drawn down from C7 and up from the base

of the lumbar spine. These evaluate the deviation of the head over the sacrum in both the coronal and sagittal planes.

- Flexion/extension angle refers to a derived angle of trunk inclination in the sagittal plane.

Derived measures of kyphosis and lordosis are also calculated by the ISIS-2 system but these were not used in this study.

Previous studies have reported that ISIS-2 measurements are reliable [2] and that they correlate well with Cobb angle [1, 3, 4], predict curve progression, and can discriminate between surgical and non-surgical candidates [3].

Normative values for ISIS-2 measures have previously been established in non-scoliotic UK school children between 10-16 years of age (n=271) [5]. No statistically significant differences between sex or age groups were encountered within this cohort (Table 7.4). The results for lateral asymmetry are similar to those reported in a previous study (mean 14.1 degrees, 95% CI 11.7, 16.5) which examined a convenience sample of 48 non-scoliotic adults (age 18-40ys) [6]. Both of these studies used an earlier version of ISIS.

Table 7.4 Normative values for ISIS measurements

age group	n	Lateral asymmetry angle (max)	Volumetric asymmetry (max)	Transverse rotation angle
10	38	10.76 (4.87)	7.65 (7.95)	5.71 (2.60)
11	56	10.66 (7.11)	8.87 (8.03)	6.11 (2.59)
12	44	10.88 (6.43)	6.18 (5.98)	5.34 (1.76)
13	37	10.45 (9.96)	8.77 (7.42)	6.09 (2.30)
14	27	12.66 (5.75)	7.84 (5.98)	5.91 (2.39)
15	28	10.75 (4.48)	9.20 (7.94)	6.10 (2.19)
16	41	11.99 (3.90)	8.34 (8.17)	5.66 (2.26)
Overall	271	11.05 (5.88)	8.15 (7.40)	5.80 (2.32)

*calculated from Carr et al 1991 [5]

Information regarding all other measures has been described in chapters 3 and 4 with supporting information provided in appendices 4 to 18.

7.2.3 Statistical analysis

Data analysis was performed using the IBM SPSS Statistics (version 22) software package. Categorical variables were summarised into frequency tables. Descriptive statistics (including 95% confidence intervals where appropriate) were calculated for all continuous variables with relevant histograms and boxplots.

To evaluate possible associations between spinal deformity and measures of body schema, scatter plots were drawn with regression lines and correlation coefficients calculated using parametric or non-parametric methods (Pearson's r and Spearman's rho respectively) depending on whether data was normally distributed.

Point-biserial correlations were used to evaluate relationships between continuous and categorical data. Bootstrapping was used when the continuous variable was not normally distributed.

8 Research question 2 - correlational analysis (results)

The previous chapter outlined the methodology to be used for the cross-sectional correlation study conducted as part of this thesis. This chapter presents the results of the study, initially focussing on the relationship between x-ray and measures of body schema. It then reviews the relationship between measures of spinal deformity as evaluated by surface topography (ISIS-2) and body schema. As this is an exploratory study, relationships between spinal deformity and other measures are also evaluated. A brief summary of the findings, along with a discussion of the limitations, completes the chapter.

8.1 Participants

Of the 58 participants with AIS recruited for the case control study, x-ray results were available for 57 participants (98.3%). X-ray information was not available for 1 participant as they had undergone radiological examination at another (non-study) centre prior to being included in the study (Table 8.1).

Results of surface topography measures were available for 30 participants (51.7%). Despite all 4 centres having access to ISIS-2 scanners, surface topography was not always collected as part of routine investigations at each site. Problems with the ISIS-2 scanner not always being available for use in some centres also limited the number of participants who underwent this form of imaging.

Table 8.1 X-ray and ISIS-2 information available by site

Site	Recruited, n	X-ray, n (%)	ISIS-2, n (%)
Royal Orthopaedic Hospital, Birmingham	20	19 (95)	6 (30)
Nuffield Orthopaedic Centre, Oxford	20	20 (100)	7 (35)
Frenchay Hospital, Bristol	11	11 (100)	10 (91)
James Cook University Hospital, Middlesbrough	7	7 (100)	7 (100)
total	58	57 (98)	30 (52)

8.2 Imaging information

Summary information of x-ray results was presented in chapter 6 (section 6.2.3). Equivalent information for ISIS-2 measures is described in Table 8.2 and Figure 8.1 to Figure 8.5. For a full explanation of ISIS-2 measures, please refer to Appendix 20.

Table 8.2 ISIS-2 measures - descriptive statistics

Variable	n	mean	SD	SE	95% CI	median	min	max	IQR	missing n (%)
Lateral asymmetry (°)	30	24.37	9.16	1.67	20.95, 27.79	22.5	9.0	44.0	17.5, 34	28 (48.3)
Volumetric asymmetry	30	17.27	10.8	1.97	13.24, 21.30	13.0	5.0	53.0	10, 21.3	28 (48.3)
Coronal balance (mm)	30	14.63	9.72	1.77	11.00, 18.26	13.0	0	37.0	7, 24.3	28 (48.3)
Transverse rotation (°)	30	2.67	2.07	0.38	1.89, 3.44	2.0	0	9.0	1, 3	28 (48.3)
Flexion angle (°)	30	1.93	1.72	0.31	1.29, 2.58	1.0	0	7.0	1,3	28 (48.3)

Figure 8.1 ISIS-2 Lateral asymmetry - histogram & boxplot

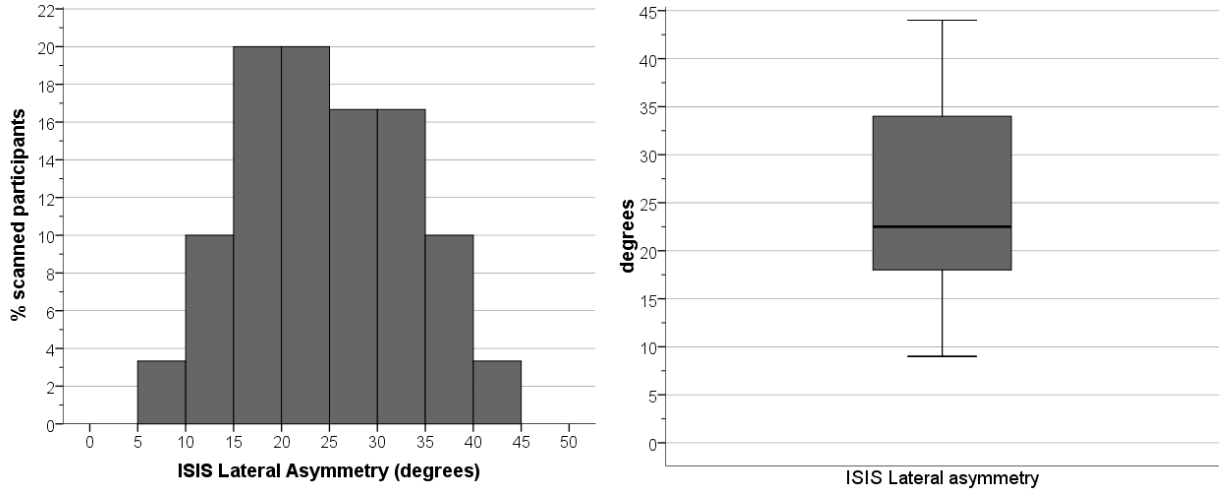


Figure 8.2 ISIS-2 Volumetric asymmetry - histogram & boxplot

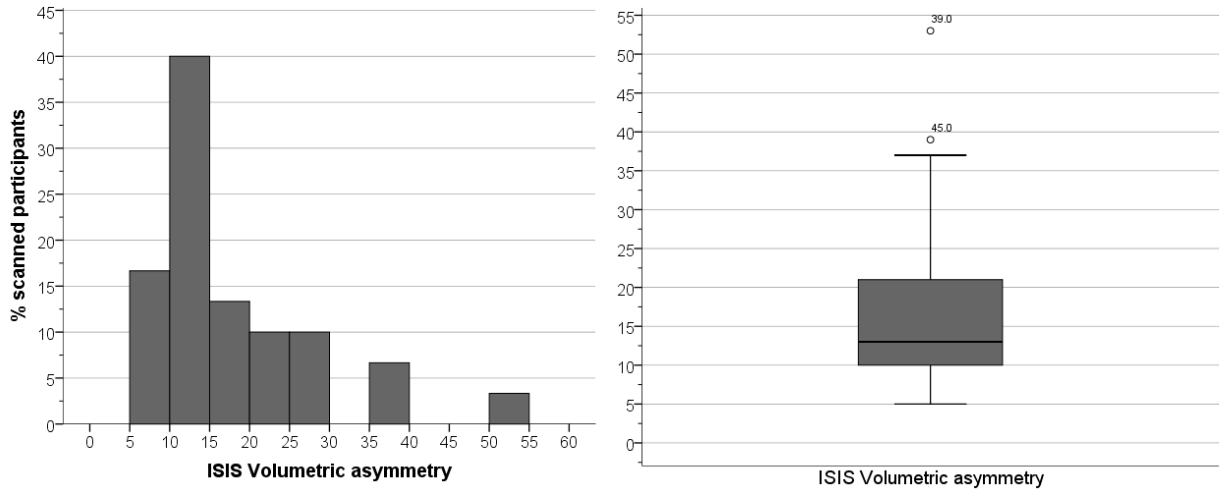


Figure 8.3 ISIS-2 Coronal balance (absolute values) - histograms & boxplots

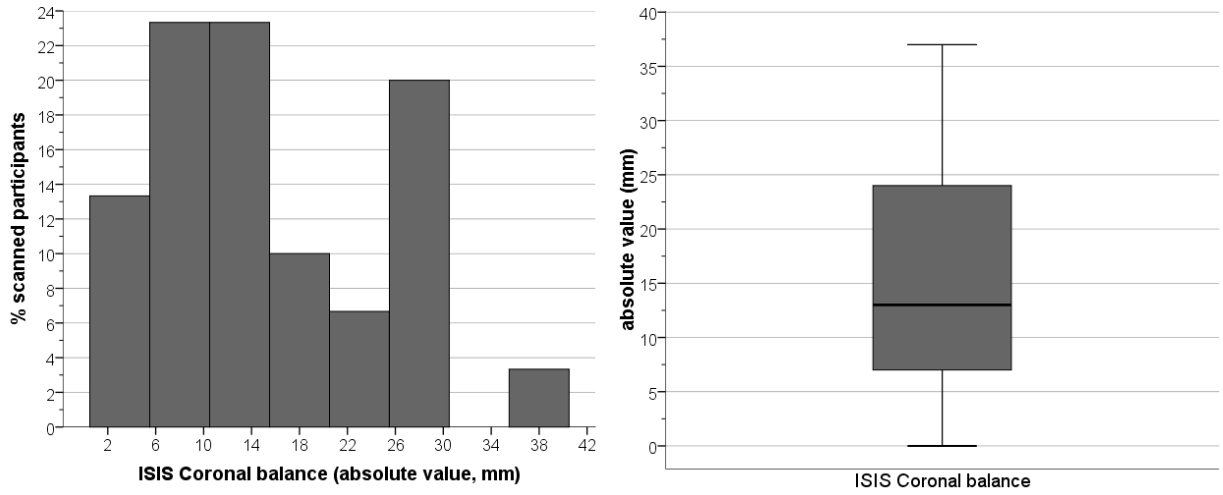


Figure 8.4 ISIS-2 Transverse rotation (absolute values) - histogram & boxplot

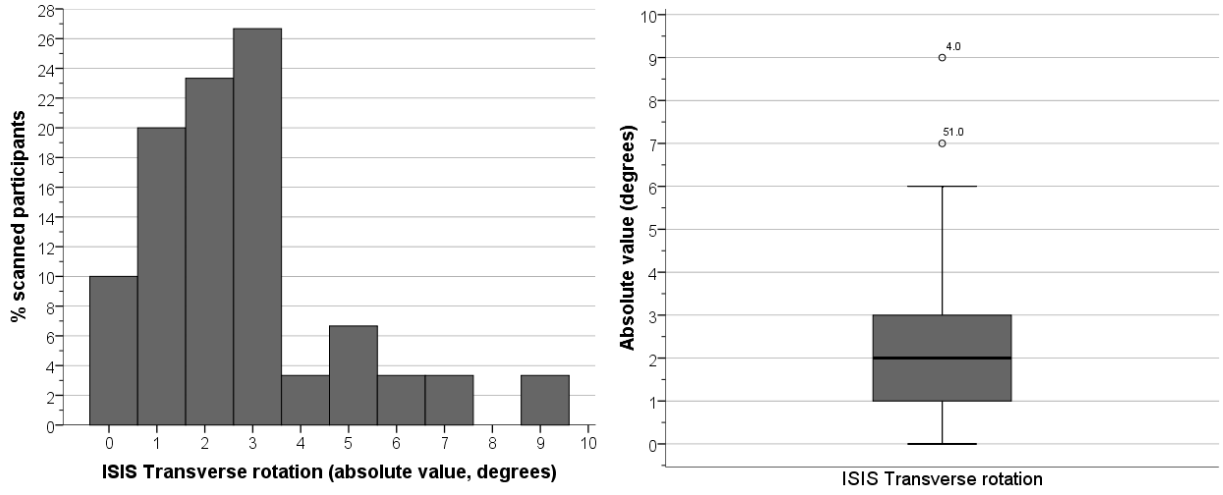
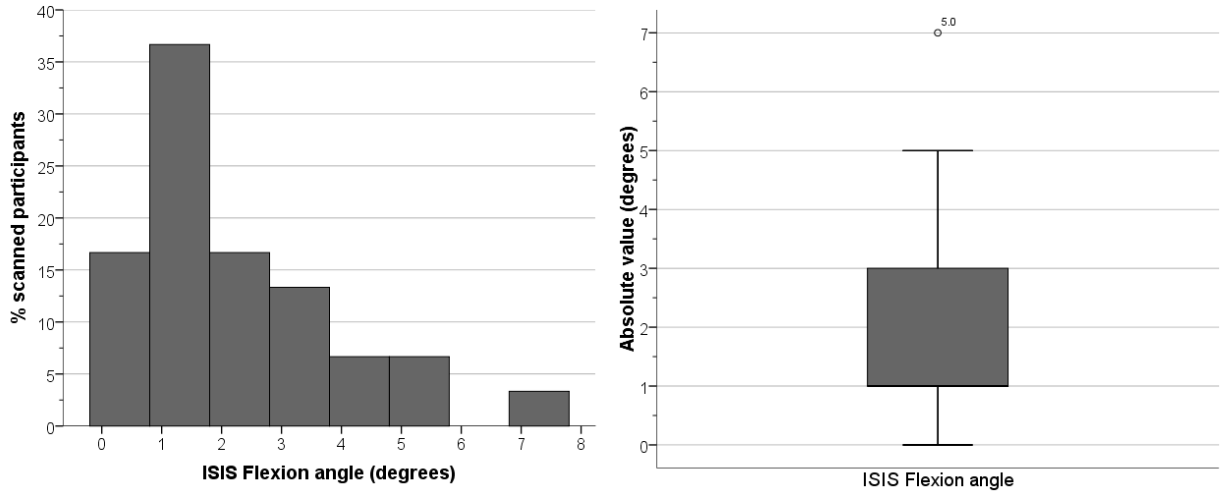


Figure 8.5 ISIS-2 Flexion angle (absolute value) - histogram & boxplot



8.2.1 X-ray v ISIS-2

Scatterplots of x-ray versus ISIS-2 measures with regression lines are presented in Figure 8.6 and Figure 8.7. The plots suggested a linear relationship between Cobb angle and both lateral asymmetry and volumetric asymmetry (Figure 8.6, statistically significant correlations displayed). Lateral asymmetry is the ISIS-equivalent of the Cobb angle (see Appendix 20).

A similar relationship appeared to exist between coronal balance (as defined by x-ray) and the equivalent ISIS-2 measure of coronal balance (Figure 8.7). There did not appear to be any other observable relationships between x-ray and ISIS-2 variables.

These observations were confirmed by correlation coefficients that were calculated between x-ray and ISIS-2 measures (Table 8.3). Strong positive correlations were found between Cobb angle and lateral asymmetry (r=.710, 95% CI .452-.873, p<0.001) with the Cobb angle sharing 50.4% of the variability with lateral asymmetry (r^2=0.504).

Moderate positive correlations between Cobb angle and volumetric asymmetry (r=.560, 95% CI .250-.769, p=0.001), as well as between coronal balance variables (r=.479, 95% CI .162-.727, p=0.007) were also reported. The percentage of shared variability was 31.4 and 24.1% respectively (r^2=0.314 and 0.241).

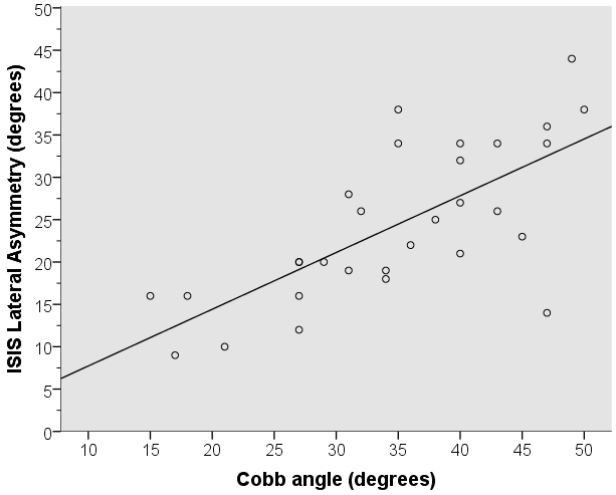
No other statistically significant correlations were reported between x-ray and ISIS-2 variables.

Table 8.3 X-ray v ISIS-2 variables - correlations

	ISIS-2 variables				
X-ray variables	**Lateral asymmetry**	**Volumetric asymmetry**	**Transverse rotation**	**Coronal balance**	**Flexion angle**
Cobb angle (°)					
Pearson Correlation	**.710****	**.560**¥**	.140¥	.041	.044¥
p-value	<0.001	.001	.462	.830	.816
BCa 95% Confidence Intervals§	.452 .873	.250 .769	-.179 .465	-.326 .371	-.359 .424
n	30	30	30	30	30
Coronal balance (mm)					
Pearson Correlation	-.182	-.118¥	-.306¥	**.479****	-.127¥
p-value	.335	.534	.100	.007	.505
BCa 95% Confidence Intervals§	-.528 .191	-.470 .237	-.589 .010	.162 .727	-.507 .283
n	30	30	30	30	30
Sagittal balance (mm)					
Spearman's rho	-.142	-.119	.078	.110	.232
p-value	.508	.580	.716	.610	.276
BCa 95% Confidence Intervals§	-.469 .213	-.513 .247	-.427 .577	-.366 .487	-.184 .584
n	24	24	24	24	24

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); § bootstrap (1000 samples) Bias Corrected accelerated 95% CIs; ¥ Spearman's rho

Figure 8.6 X-ray Cobb angle v ISIS-2 variables - scatterplots



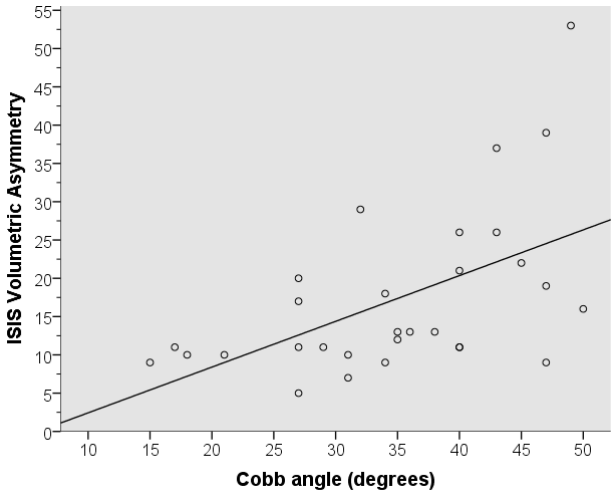
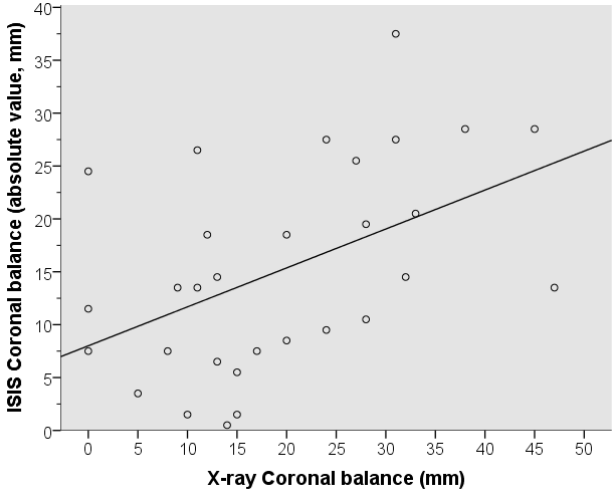


Figure 8.7 X-ray Coronal balance v ISIS-2 variables - scatterplots



8.3 Spinal deformity v body schema measures

Spinal deformity was evaluated by both x-ray and, in a subset of participants, by surface topography using ISIS-2.

8.3.1 X-ray v body schema measures

No clear linear relationships were observed from the scatterplots between x-ray variables and measures of body schema. This was confirmed by the lack of statistically significant correlations between these sets of variables (Table 8.4). The relationships that came closest to being statistically significant were between Cobb angle and TPDT, proprioception, and laterality (accuracy and reaction time) for the back. However, even these displayed only weak correlations (largest r=-.266) and the wide 95% CIs highlight the large variability. No changes in the results were seen when partial correlations were performed to control for age, disease duration, puberty status and Cobb angle.

8.3.2 ISIS-2 v body schema measures

Review of the scatterplots suggested that, similar to the x-ray results, the majority of ISIS-2 variables did not appear to share a relationship with measures of body schema..

However, statistically significant correlations were subsequently calculated between some of these variables (Table 8.5). A moderate positive correlation was calculated for coronal balance and line bisection error (r=.474, 95% CI .069, .748, p=0.008) (Figure 8.8). The percentage of shared variability between these variables was 22.5% (r^2= 0.225).

A weak negative correlation was observed between coronal balance and laterality accuracy of the hands (r= -.374, 95% CI -.697, .004, p=0.042) (Figure 8.8). The shared variability of 14% highlights the weakness of this relationship (r^2=0.14). A moderate positive correlation was also reported between transverse rotation angle and line bisection error (r=.422, 95% CI .081, .707, p=0.020) with a shared variability of 17.8% (r^2=0.178) (Figure 8.9). All of these correlations exhibited very wide confidence intervals.

The direction of the correlations suggest that greater spinal deformity (i.e. increasing coronal imbalance) is associated with worsening of these measures of body schema. These results

were consistent when partial correlations were performed to control for age, disease duration, puberty status and Cobb angle.

Table 8.4 X-ray v measures of Body Schema - correlations

X-ray variable	mm	n correct	absolute error (%)	absolute error (%)	Accuracy Hands (%)	Reaction time Hands (msec)	Accuracy back (%)	Reaction time Back (msec)	seconds
Cobb angle (°)									
Pearson Correlation	-.266	-.183	-.243	0.172¥	.092	-.138	.244¥	-.236¥	.178
p-value	.070	.176	.068	0.201	.496	.314	.067	.077	.189
BCa 95% Confidence Intervals§	-.540 .025	-.388 .036	-.475 .030	-0.091 0.414	-.199 .350	-.359 .089	-.066 .502	-.476 .052	-.106 .383
n	47	56	57	57	57	55	57	57	56
Coronal balance (mm)									
Pearson Correlation	-.045	.081	.067	.041¥	-.237	-.009	-.022¥	.056¥	.148
p-value	.768	.559	.627	.764	.081	.951	.872	.683	.286
BCa 95% Confidence Intervals§	-.389 .368	-.181 .339	-.247 .356	-.217 .320	-.426 -.031	-.273 .287	-.280 .257	-.194 .297	-.126 .410
n	45	54	55	55	55	53	55	55	54
Sagittal balance (mm)									
Spearman's rho	.214	-.177	.080	.181	-.128	-.061	-.085	-.172	-.005
p-value	.202	.262	.614	.252	.419	.701	.591	.276	.975
BCa 95% Confidence Intervals§	-.157 .536	-.518 .205	-.253 .415	-.131 .471	-.446 .235	-.382 .285	-.367 .198	-.476 .172	-.344 .350
n	37	42	42	42	42	42	42	42	41

§ bootstrap (1000 samples) Bias Corrected accelerated 95% CIs; ¥ Spearman's rho

Table 8.5 ISIS-2 variables v measures of Body Schema - correlations

	TPDT	Localisation	Proprioception	Line Bisection	Laterality				Standing balance
ISIS-2 variable	mm	n correct	absolute error (%)	absolute error (%)	Accuracy Hands (%)	Reaction time Hands (msec)	Accuracy back (%)	Reaction time Back (msec)	seconds
Lateral asymmetry (°)									
Pearson Correlation	-.318	.009	-.089	-.065¥	.254	-.133	.332¥	-.164¥	.158
p-value	.122	.961	.640	.733	.175	.492	.073	.386	.413
BCa 95% Confidence Intervals§	-.581 -.005	-.334 .309	-.440 .346	-.481 .345	-.115 .557	-.432 .212	-.099 .694	-.510 .197	-.176 .478
n	25	30	30	30	30	29	30	30	29
Volumetric asymmetry									
Spearman's rho	-.197	-.242	-.045	.034	.151	-.064	.212	.025	-.036
p-value	.345	.197	.815	.858	.427	.741	.261	.897	.854
BCa 95% Confidence Intervals§	-.571 .204	-.549 .095	-.405 .324	-.367 .424	-.259 .503	-.425 .341	-.209 .592	-.341 .383	-.388 .328
n	25	30	30	30	30	29	30	30	29
Coronal balance (mm)									
Pearson Correlation	.256	.133	.282	**.474**¥**	**-.374***	-.075	-.320¥	.096¥	.115¥
p-value	.216	.484	.131	.008	.042	.694	.085	.615	.553
BCa 95% Confidence Intervals§	-.015 .516	-.177 .415	-.048 .606	.069 .748	-.697 .004	-.344 .360	-.606 .012	-.355 .496	-.307 .512
n	25	30	30	30	30	30	30	30	30

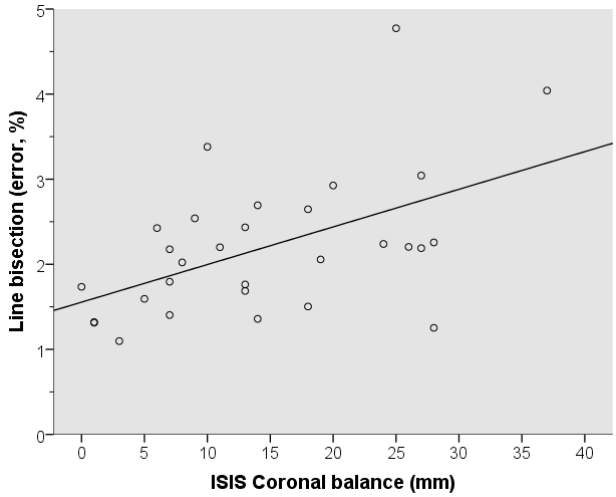
* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); § bootstrap (1000 samples) Bias Corrected accelerated 95% CIs; ¥ Spearman's rho

Table 8.5 continued

ISIS-2 variable	TPDT mm	Localisation n correct	Proprioception absolute error (%)	Line Bisection absolute error (%)	Laterality Accuracy Hands (%)	Laterality Reaction time Hands (msec)	Laterality Accuracy back (%)	Laterality Reaction time Back (msec)	Standing balance seconds
Transverse rotation (°)									
Spearman's rho	.084	.043	.099	**.422***	.179	.024	-.174	-.024	-.276
p-value	.689	.821	.604	.020	.343	.903	.358	.899	.148
BCa 95% Confidence Intervals§	-.405 .515	-.346 .401	-.278 .481	.081 .707	-.205 .480	-.383 .399	-.491 .150	-.428 .369	-.578 .053
n	25	30	30	30	30	29	30	30	29
Flexion angle (°)									
Spearman's rho	-.285	-.288	-.263	.226	.006	-.081	-.160	.203	-.234
p-value	.168	.123	.159	.230	.974	.678	.398	.282	.223
BCa 95% Confidence Intervals§	-.653 .168	-.633 .120	-.595 .128	-.133 .553	-.288 .333	-.450 .309	-.478 .233	-.152 .542	-.608 .219
n	25	30	30	30	30	29	30	30	29

* Correlation is significant at the 0.05 level (2-tailed); § bootstrap (1000 samples) Bias Corrected accelerated 95% CIs

Figure 8.8 ISIS-2 Coronal balance v body schema measures - scatterplots



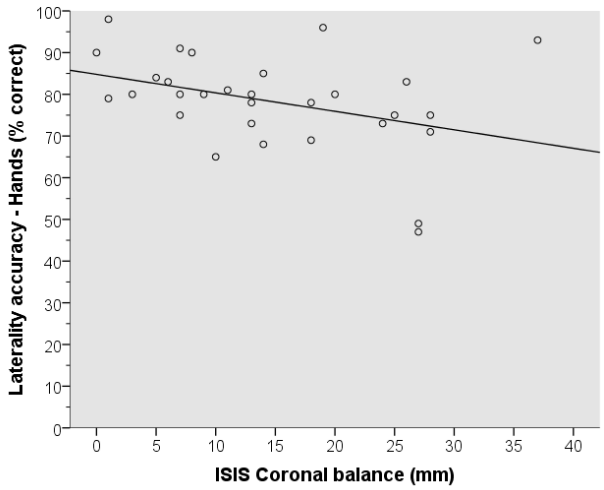
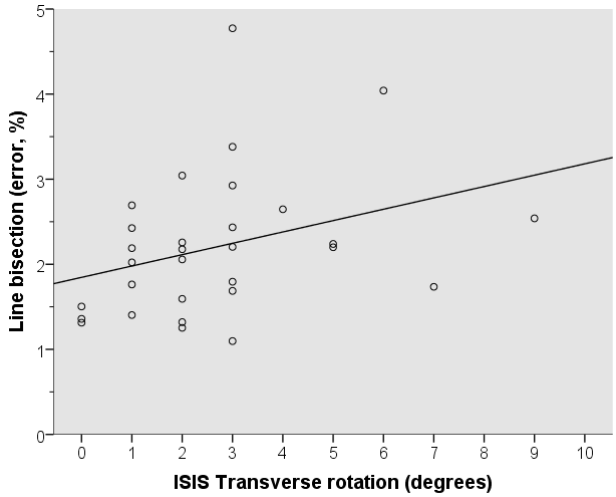


Figure 8.9 ISIS-2 Transverse rotation v body schema measures - scatterplots



8.4 Spinal deformity v other measures

Although not the main focus of the study, and this being part of an exploratory series of research, possible associations between spinal deformity and other self-report measures were also considered. These included measures of perception of trunk appearance/symmetry, HRQoL, general function and kinaesthetic/proprioceptive awareness that were also collected as part of the case control study (see section 5.2.4). Information regarding calculated correlation coefficients is presented along with scatterplots that displayed statistically significant relationships.

8.4.1 X-ray v other measures

Scatterplots that suggested possible relationships between x-ray variables and other self-report measures were plotted. The plots indicate a linear relationship between Cobb angle and the SAQ appearance scale and SAQ total score.

Calculation of correlation coefficients revealed a weak positive correlation between Cobb angle and the SAQ appearance scale which was statistically significant (r=.372, 95% CI .161, .541, p=0.005) (Table 8.6). Cobb angle shared 13.8% of variability with the SAQ appearance scale (r^2=0.138).

A similar association was also found between Cobb angle and the SAQ total score (r=.331, 95% CI .062, .539, p=0.015, r^2=0.110), a result driven by the appearance scale which makes the greatest contribution to the total score. This suggests that as Cobb angle increases, the perception of trunk appearance and symmetry worsen. These results were consistent when partial correlations were performed to control for age, disease duration and puberty status.

No other observable or statistically significant correlations were noted between x-ray variables and other self-report measures. Point bi-serial correlations between x-ray variables and EQ5D domains did not reveal any statistically significant correlations.

Table 8.6 X-ray v other measures - correlations

	SAQ			SRS-22r					
X-ray variable	appearance	expectation	total	function	pain	self-image	mental health	total	total
Cobb angle (°)									
Pearson Correlation	**.372****	.154	**.331***	.099¥	.106¥	.036	-.020¥	.058	.257
p-value	.005	.262	.015	.468	.437	.791	.883	.670	.059
BCa 95% Confidence Intervals§	.161 .541	-.119 .417	.062 .539	-.170 .359	-.176 .368	-.200 .264	-.265 .229	-.227 .318	.009 .504
n	55	55	54	56	56	56	56	56	55
Coronal balance (mm)									
Pearson Correlation	.124	.206	.184	-.094¥	-.117¥	-.142	-.210¥	-.171	.094
p-value	.375	.139	.192	.499	.401	.305	.127	.215	.503
BCa 95% Confidence Intervals§	-.237 .469	-.078 .434	-.142 .483	-.339 .188	-.409 .161	-.447 .205	-.469 .097	-.459 .132	-.182 .354
n	53	53	52	54	54	54	54	54	53
Sagittal balance (mm)									
Spearman's rho	-.009	-.121	-.071	-.149	.107	-.090	.036	-.055	.023
p-value	.957	.457	.669	.352	.507	.574	.825	.733	.888
BCa 95% Confidence Intervals§	-.344 .300	-.480 .248	-.416 .281	-.491 .183	-.211 .427	-.374 .174	-.266 .354	-.359 .250	-.330 .381
n	40	40	39	41	41	41	41	41	40

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); § bootstrap (1000 samples) Bias Corrected accelerated 95% CIs; ¥ Spearman's rho

Table 8.6 continued

X-ray variable	PODCI						EQ5D
	Upper extremity & PhysFunc	Transfers	Sports PhysFunc	Global function	Pain	Happiness	VAS
Cobb angle (°)							
Pearson Correlation	.066¥	-.119¥	.217¥	.095¥	-.005	-.050¥	-.148¥
p-value	.627	.382	.108	.486	.973	.717	.278
BCa 95% Confidence Intervals§	-.168 .281	-.382 .128	-.028 .454	-.164 .352	-.255 .229	-.335 .257	-.402 .135
n	56	56	56	56	56	56	56
Coronal balance (mm)							
Pearson Correlation	-.125¥	-.133¥	.053¥	-.071¥	-.077	-.204¥	-.133¥
p-value	.367	.338	.702	.608	.579	.140	.338
BCa 95% Confidence Intervals§	-.414 .160	-.418 .170	-.213 .335	-.383 .248	-.337 .198	-.468 .080	-.403 .162
n	54	54	54	54	54	54	54
Sagittal balance (mm)							
Spearman's rho	-.060	-.005	-.062	.053	.039	.046	-.088
p-value	.712	.977	.700	.743	.808	.775	.584
BCa 95% Confidence Intervals§	-.367 .266	-.323 .326	-.391 .299	-.306 .449	-.256 .311	-.295 .365	-.420 .253
n	41	41	41	41	41	41	41

§ bootstrap (1000 samples) Bias Corrected accelerated 95% CIs; ¥ Spearman's rho

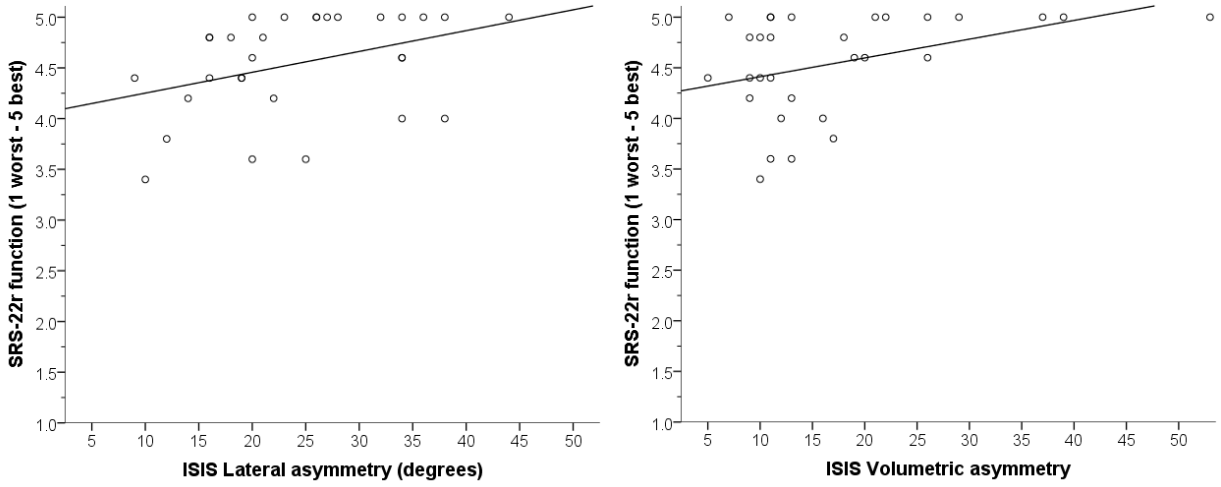
8.4.2 ISIS-2 v other measures

Calculation of correlation coefficients suggested statistically significant relationships between some ISIS-2 variables (lateral and volumetric asymmetry) with various SRS-22r and PODCI subscales (Table 8.7)

However, visualisation of the scatterplots revealed that these were driven in large part by ceiling effects in some subscales of the SRS-22r (Table 8.10) and PODCI (Figure 8.11). Maximum scores in these scales were found across the range of lateral and volumetric asymmetry angles. The direction of the implied relationships is also counterintuitive, with better self-report scores associated with greater spinal deformity. Therefore, there does not appear to be a genuine relationship between ISIS-2 and these measures despite the results of the statistical analysis.

No other observable or statistically significant relationships were found. Point bi-serial correlations between ISIS-2 variables and EQ5D domains did not reveal any statistically significant correlations.

Figure 8.10 ISIS-2 v SRS-22r - scatter plots



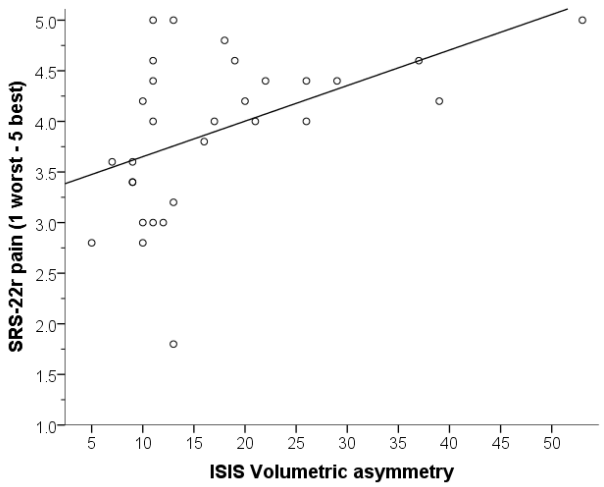
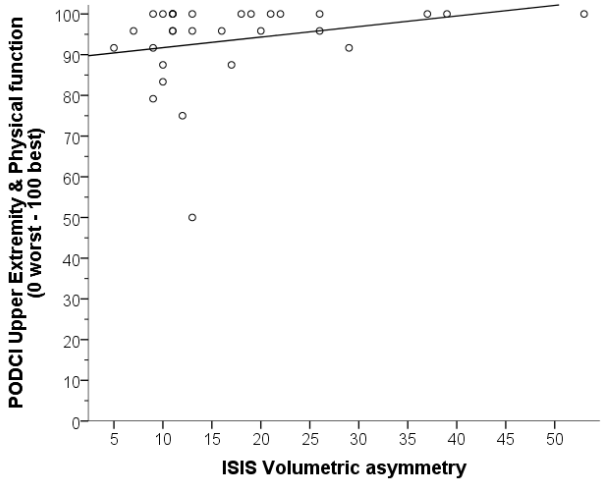
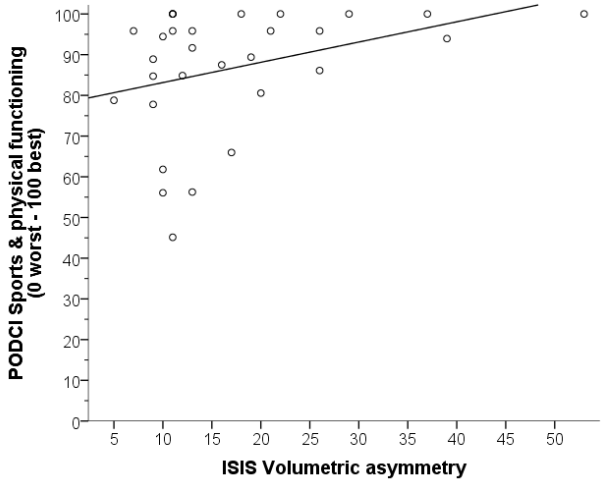
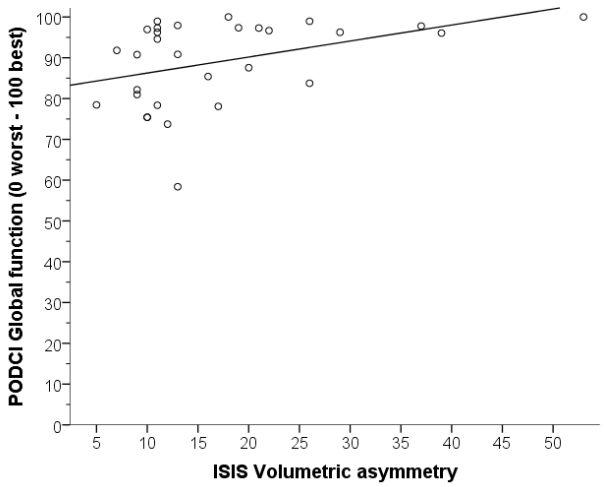


Figure 8.11 ISIS-2 v PODCI - scatter plots







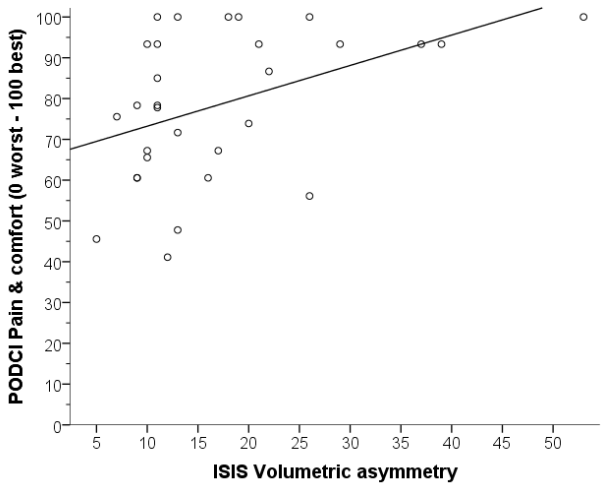


Table 8.7 ISIS-2 v other measures - correlations

	SAQ			SRS-22r					KPAQ
ISIS-2 variable	appearance	expectation	total	function	pain	self-image	mental health	total	total
Lateral asymmetry (°)									
Pearson Correlation	.193	-.031	.127	**.452*¥**	.305¥	.226	.034¥	.262	-.019
p-value	.316	.872	.510	.012	.101	.231	.857	.161	.922
BCa 95% Confidence Intervals§	-.201 .595	-.380 .361	-.256 .459	.104 .747	-.012 .593	-.167 .559	-.286 .367	-.108 .575	-.344 .302
n	29	30	29	30	30	30	30	30	30
Volumetric asymmetry									
Spearman's rho	-.025	.028	.000	**.398***	**.540****	.287	.113	.354	.013
p-value	.897	.882	.998	.029	.002	.124	.553	.055	.944
BCa 95% Confidence Intervals§	-.374 .314	-.388 .415	-.352 .358	.035 .700	.301 .703	-.063 .592	-.190 .390	.051 .601	-.368 .398
n	29	30	29	30	30	30	30	30	30
Coronal balance (mm)									
Pearson correlation	.001	-.102	-.076	-.154¥	.043¥	.074	.056¥	.055	.256
p-value	.995	.592	.694	.416	.822	.699	.770	.774	.172
BCa 95% Confidence Intervals§	-.406 .533	-.483 .390	-.502 .461	-.475 .155	-.400 .476	-.425 .537	-.363 .455	-.384 .409	-.146 .616
n	29	30	29	30	30	30	30	30	30

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); § bootstrap (1000 samples) Bias Corrected accelerated 95% CIs; ¥ Spearman's rho

Table 8.7 continued

ISIS-2 variable	PODCI						EQ5D
	Upper extremity & PhysFunc	Transfers	Sports PhysFunc	Global function	Pain	Happiness	VAS
Lateral asymmetry (°)							
Pearson Correlation	.283¥	.159¥	.315¥	.311¥	.200	.095¥	-.003¥
p-value	.129	.403	.090	.094	.289	.617	.989
BCa 95% Confidence Intervals§	-.079 .614	-.244 .541	.004 .575	-.080 .701	-.197 .560	-.248 .417	-.363 .326
n	30	30	30	30	30	30	30
Volumetric asymmetry							
Spearman's rho	**.365***	.108	**.398***	**.447***	**.438***	.103	-.075
p-value	.047	.570	.030	.013	.015	.589	.694
BCa 95% Confidence Intervals§	.031 .639	-.226 .395	.057 .668	.142 .660	.089 .704	-.220 .425	-.425 .311
n	30	30	30	30	30	30	30
Coronal balance (mm)							
Pearson's correlation	-.048¥	-.029¥	-.024¥	.033¥	.002	.012¥	.016¥
p-value	.802	.877	.900	.861	.990	.950	.934
BCa 95% Confidence Intervals§	-.391 .341	-.323 .278	-.396 .374	-.364 .395	-.421 .344	-.402 .431	-.365 .390
n	30	30	30	30	30	30	30

* Correlation is significant at the 0.05 level (2-tailed); § bootstrap (1000 samples) Bias Corrected accelerated 95% CIs; ¥ Spearman's rho

Table 8.7 continued

ISIS-2 variable	SAQ			SRS-22r					KPAQ
	appearance	expectation	total	function	pain	self-image	mental health	total	total
Transverse rotation (°)									
Spearman's rho	-.009	.015	-.025	.134	.140	.145	.280	.189	.331
p-value	.962	.939	.899	.481	.461	.446	.135	.318	.074
BCa 95% Confidence Intervals§	-.337 .318	-.401 .440	-.406 .315	-.287 .528	-.241 .521	-.233 .517	-.073 .580	-.206 .537	-.053 .633
n	29	30	29	30	30	30	30	30	30
Flexion angle (°)									
Spearman's rho	.064	.039	.061	.223	.092	.145	.178	.196	.051
p-value	.743	.837	.752	.236	.630	.445	.346	.299	.789
BCa 95% Confidence Intervals§	-.301 .388	-.379 .468	-.361 .461	-.201 .555	-.233 .400	-.235 .478	-.163 .505	-.170 .515	-.287 .364
n	29	30	29	30	30	30	30	30	30

§ bootstrap (1000 samples) Bias Corrected accelerated 95% CIs

Table 8.7 continued

ISIS-2 variable	PODCI						EQ5D
	Upper extremity & PhysFunc	Transfers	Sports PhysFunc	Global function	Pain	Happiness	VAS
Transverse rotation (°)							
Spearman's rho	.254	.270	.084	.182	.101	.072	.024
p-value	.175	.149	.660	.336	.594	.705	.902
BCa 95% Confidence Intervals§	-.117 .560	-.104 .622	-.279 .472	-.202 .517	-.256 .433	-.290 .405	-.337 .415
n	30	30	30	30	30	30	30
Flexion angle (°)							
Spearman's rho	.107	.039	.179	.006	-.066	-.042	-.147
p-value	.572	.838	.345	.975	.729	.824	.437
BCa 95% Confidence Intervals§	-.276 .473	-.343 .386	-.193 .496	-.374 .388	-.456 .335	-.441 .377	-.525 .265
n	30	30	30	30	30	30	30

§ bootstrap (1000 samples) Bias Corrected accelerated 95% CIs

8.4.3 Perceived spinal deformity

The results of the case control study (chapter 6) suggested that there were differences between people with AIS and non-scoliotic controls with regard to perceived spinal deformity (SAQ) and HRQoL, particularly pain and self-image and, to a lesser degree, function. However, the correlational analyses conducted in the previous sections (8.4.1 and 8.4.2) did not reveal any association between the actual magnitude of spinal deformity and these parameters. Therefore, an exploratory analysis was undertaken to investigate whether there was any relationship between perceived spinal deformity (as measured by SAQ) and HRQoL. The results are presented in Table 8.8 to Table 8.10 with relevant scatter plots (Figure 8.12 and Figure 8.13).

8.4.3.1 Pain

Calculation of correlation coefficients revealed a weak negative correlation between the SAQ appearance scale and the PODCI pain scale which was statistically significant (r=-.365; 95% CI -.622, -.089, p=0.016, r^2=0.133). A point bi-serial correlation analysis also revealed a statistically significant moderate correlation between the SAQ appearance scale and the EQ5D pain domain (r=.438, 95% CI .178, .640, p=0.03, r^2=0.192). No statistically significant correlation was observed with the SRS-22 r pain scale.

8.4.3.2 Self-image & perceived health

Statistically significant moderate negative correlations were observed between SAQ appearance and the SRS-22r self-image scales (r=-.619, 95% CI -.771, -.391, p<0.001, r^2=.383). Similar results were also reported for the PODCI happiness with physical condition scale (r=-.580, 95% CI -.775, -.310, p<0.001, r^2=.336) and the EQ5D health state VAS (r=-.466, 95% CI -.696, -.188, p=0.002, r^2=.217).

8.4.3.3 Function

Weak negative correlations were observed between SAQ appearance and various function scales of the PODCI (Upper extremity & Physical function, Transfers & mobility, Global function) and these were statistically significant (Table 8.9). However, review of the scatterplots revealed significant ceiling effects with the PODCI upper extremity and transfer scales (Figure 8.13).

Point biserial analyses revealed statistically significant weak to moderate correlations between EQ5D usual activity and mobility domains respectively (Table 8.10).

No statistically significant correlations were calculated between SAQ and measures of body schema.

Table 8.8 Correlations between SAQ scales and SRS-22r scales

			SAQ appearance	SAQ expectations	SAQ total score
SRS22 function	Spearmans rho		-.142	-.182	-.219
	Sig. (2-tailed)		.363	.244	.157
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.453	-.489	-.532
		Upper	.157	.123	.089
SRS22 pain	Spearman's rho		-.232	-.134	-.259
	Sig. (2-tailed)		.134	.392	.094
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.516	-.468	-.573
		Upper	.098	.206	.066
SRS22 self image	Pearson Correlation		**-.619****	**-.469****	**-.623****
	Sig. (2-tailed)		.000	.001	.000
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.771	-.674	-.770
		Upper	-.391	-.214	-.416
SRS22 mental health	Spearman's rho		-.237	-.283	**-.352***
	Sig. (2-tailed)		.126	.065	.021
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.533	-.553	-.590
		Upper	.074	-.007	-.098
SRS22 total score	Pearson Correlation		**-.388***	-.280	**-.383***
	Sig. (2-tailed)		.010	.069	.011
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.652	-.564	-.637
		Upper	-.078	.054	-.075

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed); bootstrap (1000 samples) Bias Corrected accelerated 95% CIs

Table 8.9 Correlations between SAQ scales and PODCI scales

			SAQ appearance	SAQ expectations	SAQ total score
PODCI UE & PhysFunc	Spearman's rho		**-.424****	**-.379***	**-.483****
	Sig. (2-tailed)		.005	.012	.001
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.657	-.595	-.689
		Upper	-.093	-.098	-.203
PODCI Transfers & Mobility	Spearman's rho		**-.353***	-.185	**-.322***
	Sig. (2-tailed)		.020	.235	.035
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.587	-.462	-.571
		Upper	-.094	.087	-.064
PODCI Pain Comfort	Pearson Correlation		**-.365***	-.234	**-.344***
	Sig. (2-tailed)		.016	.131	.024
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.622	-.517	-.595
		Upper	-.089	.059	-.064
PODCI Sports PhysFunc	Spearman's rho		-.183	-.163	-.232
	Sig. (2-tailed)		.241	.295	.135
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.458	-.465	-.532
		Upper	.097	.123	.069
PODCI Global function	Spearman's rho		**-.378***	-.282	**-.409****
	Sig. (2-tailed)		.013	.067	.006
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.627	-.559	-.668
		Upper	-.088	.022	-.106
PODCI Happiness w/ physical condition	Spearman's rho		**-.580****	**-.578****	**-.689****
	Sig. (2-tailed)		.000	.000	.000
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.775	-.769	-.829
		Upper	-.310	-.332	-.466

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed); bootstrap (1000 samples) Bias Corrected accelerated 95% CIs

Table 8.10 Correlations between SAQ scales and EQ5D domains

			SAQ appearance	SAQ expectations	SAQ total score
EQ5D pain or discomfort	Pearson Correlation		**.438****	.213	**.375***
	Sig. (2-tailed)		.003	.170	.013
	N		43	43	43
	BCa 95% Confidence Interval	Lower	.178	-.052	.115
		Upper	.640	.473	.612
EQ5D mobility	Pearson Correlation		**.451****	**.313***	**.444****
	Sig. (2-tailed)		.001	.020	.001
	N		55	55	55
	BCa 95% Confidence Interval	Lower	.178	.023	.154
		Upper	.636	.521	.624
EQ5D usual activity	Pearson Correlation		**.299***	.081	.231
	Sig. (2-tailed)		.026	.558	.090
	N		55	55	55
	BCa 95% Confidence Interval	Lower	.016	-.198	-.070
		Upper	.527	.347	.488
EQ5D health state VAS	Spearman's rho		**-.466****	-.279	**-.430****
	Sig. (2-tailed)		.002	.070	.004
	N		43	43	43
	BCa 95% Confidence Interval	Lower	-.696	-.552	-.656
		Upper	-.188	.017	-.148

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed); bootstrap (1000 samples) Bias Corrected accelerated 95% CIs

Figure 8.12 Scatterplots SAQ appearance v pain, self-image & happiness with physical condition

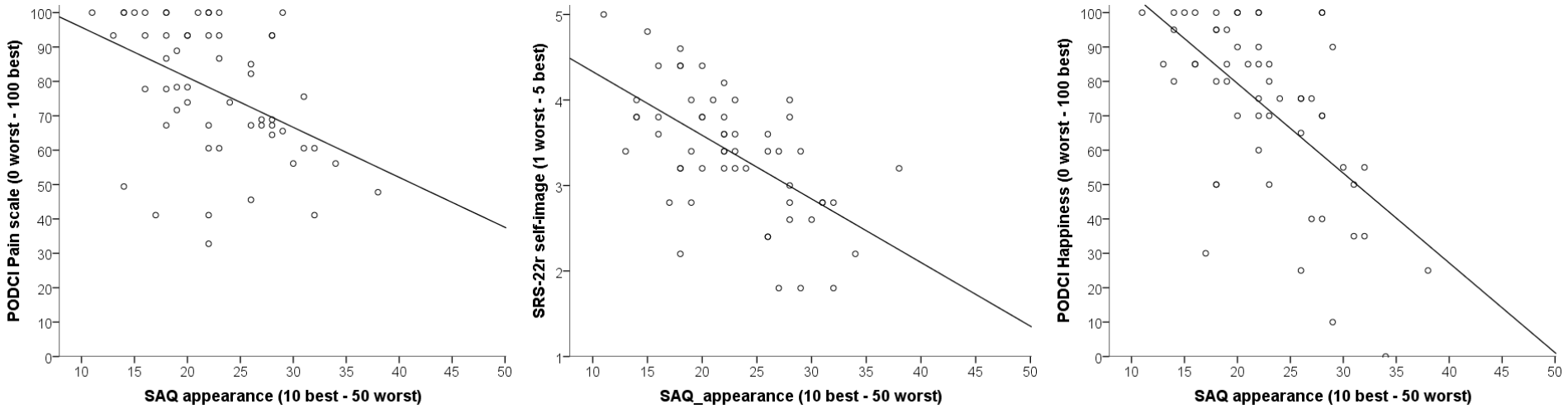
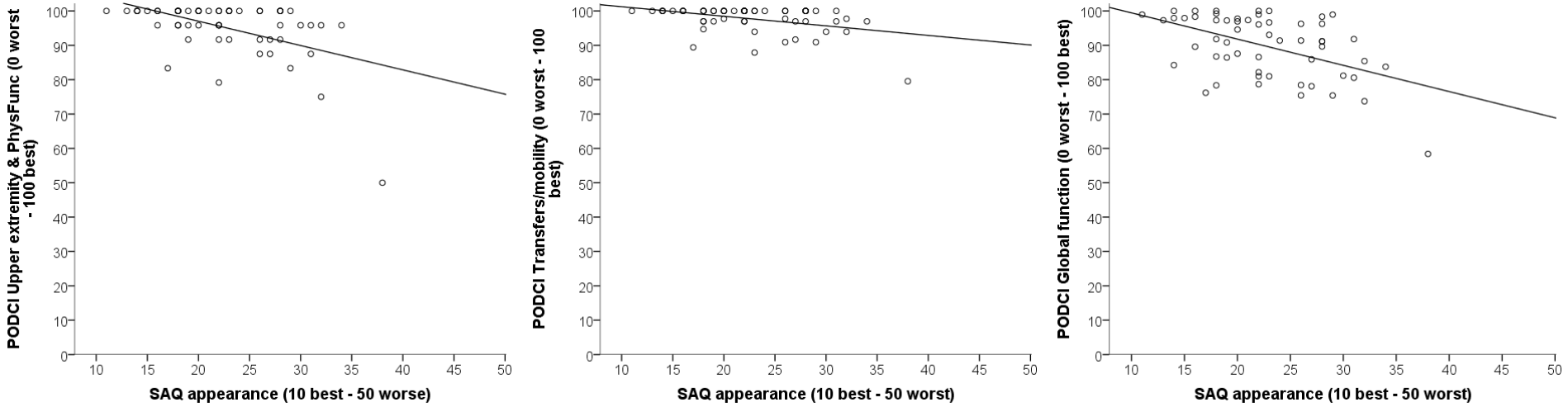


Figure 8.13 Scatterplots SAQ appearance v function measures



8.5 Summary

As described previously in section 6.2.3 and 6.5.1, the radiological characteristics of the study participants indicate that they represent a typical AIS population of this age group (i.e. 10-17 years) with moderate levels of spinal deformity, although it also included people from across the range of mild to severe scoliosis (mean Cobb angle = 34.0 degrees, SD 10.0, 95% CI 31.4, 36.7, range 14 to 50 degrees).

Unfortunately, there are no published reports of ISIS-2 measurements for non-surgical AIS patients, making it difficult to place the ISIS-2 results from the study participants in context. ISIS-2 imaging of surgical patients with AIS indicate far higher levels of pre-surgical spinal deformity than recorded here [1], with values for lateral asymmetry ranging from 45 to 76 degrees. In contrast, reported normative values for the various ISIS-2 measures in non-scoliotic adolescents [2] were approximately half that recorded by the participants in this study (see section 6.2.2.2). These results confirm the radiological findings which characterise the study cohort as suffering, on average, from moderate AIS.

Comparison of radiological and surface topography measures revealed statistically significant correlations similar to previous studies. For example, Weisz et al [3] reported a correlation (r) of 0.77 ($p<0.0001$) between lateral asymmetry and Cobb angle, which is very similar to the results of this study ($r=0.710$, $p<0.001$). However, the weak relationship between coronal balance measures from x-ray and ISIS-2 highlight the differences between actual bony changes and their visible 'surface' manifestations. The lack of correlation between other x-ray and ISIS-2 variables suggests that they are assessing different aspects of spinal deformity.

Overall, it appears that the results of spinal deformity measures used in this study from both radiological and surface topography imaging are consistent with previous reports. They also indicate that the study participants are representative of an AIS population that has not reached severe levels of deformity where surgery would be considered.

8.5.1 Spinal deformity v body schema measures

A review of the results suggests that there is no meaningful relationship between the magnitude of spinal deformity and measures of body schema such as tactile acuity, left/right

judgement, spatial perception, or proprioception. No significant correlations were reported between either x-ray or the majority of ISIS-2 variables and body schema measures. Although analyses resulted in statistically significant correlations between two ISIS-2 variables and two body schema measures, the width of the confidence intervals and the small percentage of shared variability (as defined by r^2) call into question the strength of any relationship.

8.5.2 Spinal deformity v other measures

A summary of the results indicates little or no relationship between spinal deformity and other self-report measures of HRQoL, function, or kinaesthetic/proprioceptive awareness. Although a statistically significant correlation was reported between Cobb angle and perception of trunk/spinal symmetry (SAQ appearance scale), the relationship was weak and exhibited wide confidence intervals with limited shared variability between the two measures. However, it does fit the expected pattern of greater perceived trunk asymmetry with higher levels of spinal deformity.

Of interest is the apparent lack of any corresponding relationship between surface topography measures and perception of trunk symmetry. If surface topography evaluates cosmetic aspects which are visible to the patient and therefore, more likely to be of greater concern than underlying non-visible bony changes, it would be expected that they would have a greater influence on trunk perception, illustrated by larger correlations between these parameters. The results of this study did not find such large correlations.

Other apparent relationships between ISIS-2 and HRQoL and function measures were compromised by ceiling effects in the self-report instruments used. The high scores seen in these measures also highlight the fact that moderate AIS does not seem to be associated with any clinically significant problems with function or HRQoL.

8.5.3 Perceived spinal deformity

The results of comparisons between perceived spinal deformity and measures of HRQol and function revealed statistically significant relationships. Moderate to strong correlations were observed between the SAQ appearance and SRS-22r self-image scales as well as the related PODCI happiness with physical condition scale. This suggests that in people with AIS, perceived

spinal deformity is associated with overall self-image as well as happiness with their physical condition.

Two out three of the pain measures displayed relationships with perceived spinal deformity. Although these were generally weaker than for self-image, they indicate that increased perceived spinal deformity is associated with increased pain.

The apparent relationship between perceived spinal deformity and function was compromised by the ceiling effects evident in the scatterplots for two of the three PODCI scales with statistically significant correlations. This effect was less pronounced in the PODCI global function scale and it appears that higher perceived spinal deformity has some association with lower global function scores.

8.5.4 Limitations

This study had a number of limitations that may have affected the results. Firstly, surface topography was limited to just over half of the study participants which limited the sample size to 30 participants. This is reflected in the wide 95% confidence intervals and other measures of variability. A larger sample size would reduce the level of variability and therefore strengthen the confidence in the results of the comparisons with ISIS-2 imaging measures or possibly lead to a change in the results.

Some surface topography measures are also prone to artefacts introduced by stance, breathing, posture and sway. These issues were of particular relevance in the first iteration of the ISIS scanner and were resolved to some extent with the development of ISIS-2, which uses a standardised set-up and much faster recording speeds to limit these effects [3-6]. Surface topography measures in general have also been reported to be less accurate for patients who are extremely obese or have heavy musculature [6] although the BMI results of the study participants did not indicate that this was a major problem with this cohort.

Another possible limitation relates to the timing of the imaging studies with regard to when data from other measures was collected. Study testing was timed to take place when participants were scheduled to have their routine orthopaedic consultant visits. Generally, they would also have some form of imaging conducted at the same time. However, on a number of occasions, and for a variety of different reasons, imaging did not occur at the

scheduled visit, and therefore information was collected from the imaging studies that were conducted as close to the data collection session as possible. In other cases, participants could not attend their routine orthopaedic review (with imaging) and the study data collection session on the same day, again resulting in a time gap between imaging and data collection of other study measures. However, in the main, the differences in time between imaging and data collection for the study were small and it is unlikely that any significant differences would occur over such a short period of time.

Finally, some of the measures (particularly self-report instruments) displayed clear ceiling effects with large proportions of participants recording maximum or near-maximum scores. This limits the ability to evaluate the extent of any relationships between variables and may hide actual associations between spinal deformity and the underlying domains the relevant instruments seek to measure. Although they did not appear to be appropriate for the group of participants involved in this study, it is uncertain whether use in patients with greater severity of spinal deformity would reveal any underlying relationships.

8.5.5 Conclusion

The objective of this study was to ascertain whether a relationship exists between mechanisms that are thought to underpin body schema and measures of spinal deformity in adolescents with AIS. The results indicate that no such relationship exists. They also suggest that, at least amongst people with moderate AIS where surgery is not being considered, increasing magnitudes of spinal deformity are not associated with significant increases in pain or reductions in function, self-image or other aspects of HRQoL. However, the perception of spinal deformity does appear to be related at least to some extent.

With regard to testing in people with AIS, the ceiling effects seen with some measures indicate that care should be taken when selecting appropriate measurement tools and that possibly, these may need to be tailored to differing levels of spinal deformity in AIS.

9 Research question 3 - longitudinal analysis (methods)

This chapter describes the methodology used in the longitudinal analyses conducted as part of this thesis. A brief overview of the research question the study is addressing is provided initially. The rest of this chapter then focuses specifically on the methodology with the results described in chapter 9.

9.1 Overview

9.1.1 Research question

The research questions that this thesis is seeking to answer are listed below (Table 9.1). The longitudinal analyses are concerned with answering the last of these questions.

Table 9.1 Research question - longitudinal study

Research questions	
1	do adolescents with AIS (cases) differ from non-scoliotic adolescents (controls) with regard to mechanisms that are thought to underpin body schema?
2	in adolescents with AIS, is there any relationship between the mechanisms thought to underpin body schema and the magnitude of spinal deformity?
3	is there any relationship between changes in body schema and progression of the spinal deformity in AIS over time?

9.1.2 Hypothesis tested

The hypothesis derived from the above question is that:

> H_1: *changes in measures of spinal deformity over time are associated with changes in measures of body schema.*

The null hypothesis (H_o) is that in adolescents with AIS, changes over time in spinal deformity are not associated with changes in the underlying mechanisms of body schema.

9.2 Methods - longitudinal study

9.2.1 Study design

To evaluate the study hypothesis, a longitudinal study was conducted on adolescents with AIS. Data was obtained from participants with AIS who participated in the initial case control study described in chapters 4 and 5. As well as the baseline data that was used for the cross-sectional case control and correlational studies, information was also collected at 6 and 12 months to assess changes over time.

As previously discussed, the participants with AIS that took part in the studies that make up this thesis were recruited as part of a NIHR-funded feasibility study [1]. The feasibility study involved a pilot randomised control trial (RCT) where participants were randomised on a 1:1 basis into either an exercise intervention arm or an advice (control) arm. Follow-up was performed at 6 months only. Participants in the experimental intervention were asked to perform a home exercise programme for 6 months supplemented by 6 to 9 session with a physiotherapist who monitored, modified and progressed the programme as needed as well as providing education and advice regarding AIS. The focus of the exercises was to improve the symmetry and posture of the trunk and spine. The control group received the advice and education only over 1 to 2 sessions with the physiotherapist. Further details are provided in Williams et al [1].

The objectives of the feasibility study were primarily to determine if a larger RCT could be performed by assessing recruitment rate and intervention acceptability. The sample size was not sufficient to determine the effectiveness of the interventions involved. Similarly, this longitudinal analysis did not attempt to determine the benefits of the interventions and has pooled the data from both arms for analysis. Where appropriate, treatment allocation was controlled for when conducting the statistical analyses.

The setting, methods of participant recruitment (including inclusion and exclusion criteria), potential biases and ethics have been described previously in sections 5.2.2, 5.2.3, 4.2.8 and 5.2.10 respectively.

9.2.2 Variables

Information collected from participants with AIS is described in sections 5.2.4 to 5.2.7 and listed in Tables 5.2 and 5.3. These include all the self-report and physical measures from which data was obtained for this longitudinal analysis. Information regarding radiological and surface topography imaging are outlined in sections 7.2. Detailed descriptions of all measures are provided in appendices 5 to 20.

9.2.3 Statistical analysis

Data analysis was performed using the IBM SPSS Statistics (version 22) software package. Categorical variables were summarised into frequency tables and Cochran's Q test conducted to determine differences in proportions between time points.

Descriptive statistics (including 95% confidence intervals where appropriate) were calculated for all continuous variables for each time point with relevant plots. A separate set of descriptive statistics for each time-point were also produced which included only those participants that completed the 12 month follow-up (12 mth completers).

Initially, a mixed repeated-measures analysis of variance with two predictor variables (within subject = time-point, 3 levels; between subject = trial arm, 2 levels) was used to assess statistical significance of the difference between means at each time-point. Homogeneity of variance was assessed using Levene's test. Normality of standardised residuals at all three time-points was also evaluated. Where the assumption of sphericity was violated, Greenhouse-Geisser or Huynh-Feldt estimates were used to adjust degrees of freedom. Bonferroni correction was used to adjust for multiple comparisons. One way non-parametric models (Friedman's ANOVA) were used for evaluation of independent variables where the assumptions of homogeneity and normality were violated and could not be corrected via transformations or elimination of outliers. Results were interpreted with regard to likely clinical significance.

Scatter plots of spinal deformity and measures of body schema were drawn (with regression lines) and correlation coefficients calculated for each time-point using parametric or non-parametric methods (Pearson's r and Spearman's rho respectively) depending on whether data was normally distributed. Point-biserial correlations were used to evaluate relationships

between continuous and categorical data. Bootstrapping was used when the continuous variable was not normally distributed.

The case control study conducted as part of this thesis included a number of within-group analyses of differences between sides (left v right, affected v unaffected side). Any differences recorded were generally small and either not statistically or clinically significant. Therefore, these side analyses were not conducted as part of this longitudinal study.

10 Research question 3 - longitudinal analysis (results)

The previous chapter outlined the methodology used for the longitudinal analyses conducted as part of this thesis. This chapter presents the results, initially describing the participants from whom data was collected at each time point and defining those who completed testing at the last follow-up at 12 months. It then presents the results of the longitudinal analyses as well as looking at relationships between spinal deformity and other measures at 6 and 12 months. A brief summary of the findings, along with a discussion of the limitations, completes the chapter.

10.1 Participants

10.1.1 Follow-up

The number of participants with AIS who completed assessments at each time point is listed by recruitment site in Table 10.1.

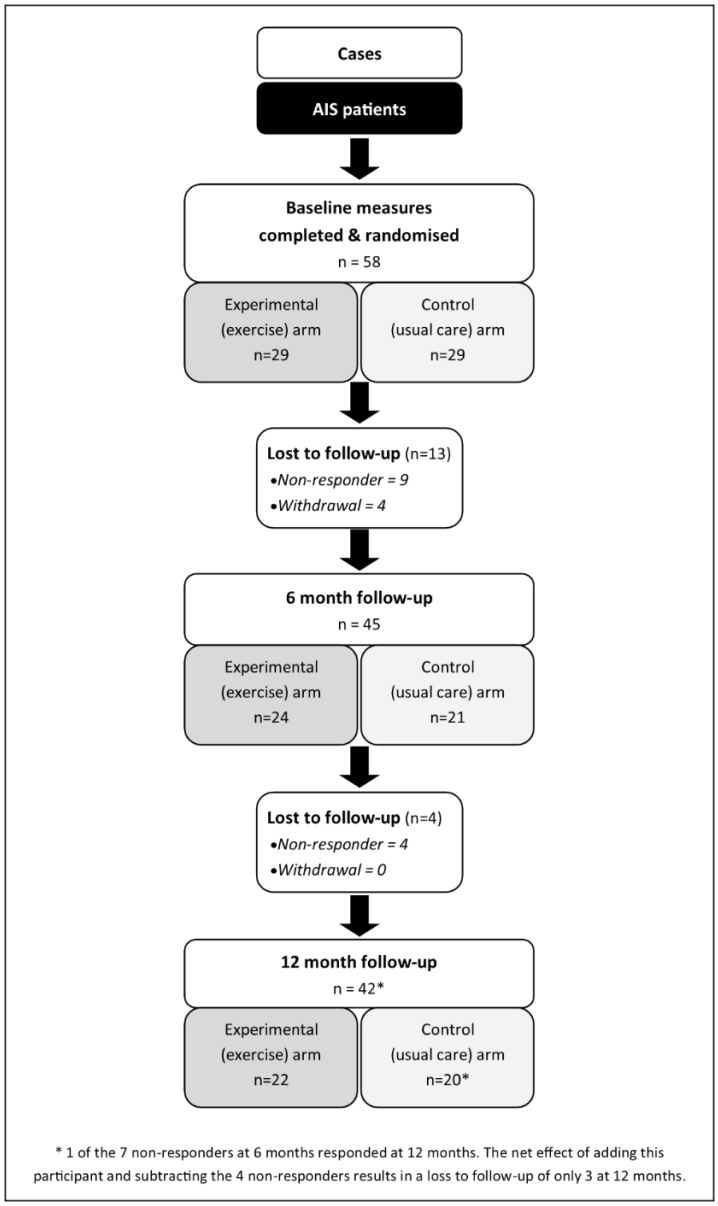
Table 10.1 Follow-up by recruitment site

site	baseline n (%)	6 months n (%)	12 months n (%)
Royal Orthopaedic Hospital, Birmingham	20 (34.5)	12 (26.7)	10 (23.8)
Nuffield Orthopaedic Centre, Oxford	20 (34.5)	16 (35.6)	16 (38.1)
Frenchay Hospital, Bristol	11 (19)	11 (24.4)	11 (26.2)
James Cook University Hospital, M'brough	7 (12)	6 (13.3)	5 (11.9)
total	58 (100)	45 (100)	42 (100)
% of baseline		77.6%	72.4%

Overall, there was a 22.4% (13/58) and 27.6% (16/58) attrition rate at 6 and 12 months respectively. Participants who didn't complete follow-up were primarily from one site (ROH) where only 60% (12/20) and 50% (10/20) of participants completed the 6 and 12 mth follow-ups respectively. Taken together, follow-up rates at the other sites were 86.8% (33/38) at 6 months and 84.2% (32/38) at 12 months. The reason for this disparity is unclear.

The consort diagram in Figure 10.1 gives a breakdown of recruitment, trial allocation and retention from inclusion into the study until final follow-up. It also details why participants were lost to follow-up, with the majority of those who did not complete failing to respond to requests to attend follow-up sessions (n=13). All but one participant who did not complete follow-up at 6 months, also failed to complete testing at 12 months.

Figure 10.1 Consort diagram longitudinal study



At each time point, some data was either not collected or lost (Table 10.2). One questionnaire was lost at baseline and a further 1 and 4 were missing at 6 and 12 months respectively, which

resulted in only having the results of the physical testing available for analysis for those participants. Postal questionnaires were completed by 1 participant at 6 months and 3 participants at 12 months. Postal responders did not undergo physical tests therefore no data for these measures is available for these participants.

Table 10.2 Missing data by outcome type

Missing data	baseline	6 months	12 months
Self-report measures only	1 (1.7%)*	1 (2.2%)*	4 (9.5%)*
Physical test results only	0	1 (2.2%)**	3 (7.1%)**
Nil missing	57 (98.3%)	43 (95.6%)	35 (83.3%)
n (completed timepoint) =	58	45	42

*missing questionnaire, ** postal response

10.1.2 Baseline characteristics - Completers v non-completers

Descriptive statistics of baseline demographic data were calculated to assess if there were any relevant baseline differences between participants who completed follow-ups at either 6 and 12 months (completers, C) and those that did not complete at each of these time-points (non-completers, NC) (Table 10.3).

Participants who completed testing at all time-points were approximately 8-9 months older than non-completers (14.5yrs C v 13.9 yrs NC) at baseline. This possibly explains the height difference between groups with non-completers on average 5-6cm shorter. Self-reported puberty onset also occurred a year earlier in non-completers (median 12 yrs NC v 13 yrs C).

On average, there were 14.8% more 6 month non-completers who had been allocated to the control trial arm than to the intervention (exercise) arm of the pilot RCT, which formed part of the NIHR-funded feasibility study. This difference was 8.6% for 12 month non-completers.

Table 10.3 Participant baseline demographic variables by responder type

	All n (%)	6 mth completer n (%)	6 mth non-completer n (%)	12 mth completer n (%)	12 mth non-completer n (%)
Gender					
Female	48 (82.8)	38 (84.4)	10 (76.9)	35 (83.3)	13 (81.3)
Male	10 (17.2)	7 (15.6)	3 (23.1)	7 (16.7)	3 (18.8)
subtotal	58 (100)	45 (100)	13 (100)	42 (100)	16 (100)
missing	0	0	0	0	0
Ethnicity					
White	52 (91.2)	41 (91.1)	11 (91.7)	39 (92.9)	13 (86.7)
Indian	0	0	0	0	0
Chinese	1 (1.8)	1 (2.2)	0	1 (2.4)	0
Mixed	0	0	0	0	0
Black/Black British	3 (5.3)	2 (4.4)	1 (8.3)	1 (2.4)	2 (13.3)
Other	1 (1.8)	1 (2.2)	0	1 (2.4)	0
subtotal	57 (100)	45 (100)	12 (100)	42 (100)	15 (1)
missing	1	0	1	0	1
Trial arm					
Control	29 (50.0)	21 (46.7)	8 (61.5)	20 (47.6)	9 (56.3)
Experimental	29 (50.0)	24 (53.3)	5 (38.5)	22 (52.4)	7 (43.8)
subtotal	58 (100)	45 (100)	13 (100)	42 (100)	16 (100)
missing	0	0	0	0	0
Handedness (EHI)					
Left	1 (1.8)	1 (2.2)	0	1 (2.4)	0
Right	50 (87.7)	40 (88.9)	10 (83.3)	37 (88.1)	13 (86.7)
Mixed	6 (10.5)	4 (8.9)	2 (16.7)	4 (9.5)	2 (13.3)
subtotal	57 (100)	45 (100)	12 (100)	42 (100)	15 (100)
missing	1	0	1	0	1
Puberty status					
Yes	46 (80.7)	36 (80.0)	10 (83.3)	35 (83.3)	11 (73.3)
No	11 (19.3)	9 (20.0)	2 (16.7)	7 (16.7)	4 (26.7)
subtotal	57 (100)	45 (100)	12 (100)	42 (100)	15 (100)
missing	1	0	1	0	1
Family history of scoliosis					
Yes	17 (38.6)	17 (39.5)	0.0	16 (39.0)	1 (33.3)
No	27 (61.4)	26 (60.5)	1 (100)	25 (61.0)	2 (66.7)
subtotal	44 (100)	43 (100)	1 (100)	41 (100)	3 (100)
missing	14	2	12	1	13

Table 10.3 continued

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Age (baseline)									
All (n=58)	14.37	1.72	0.23	13.92, 14.83	14.63	13.10, 15.85	10.33	16.92	0
6 mth C* (n=45)	14.51	1.80	0.27	13.97, 15.06	14.75	13.29, 15.96	10.33	16.92	0
6 mth NC* (n=13)	13.88	1.37	0.38	13.05, 14.71	14.08	12.88, 15.00	11.00	16.08	0
12 mth C (n=42)	14.54	1.84	0.28	13.97, 15.11	14.83	13.35, 16.06	10.33	16.92	0
12 mth NC (n=16)	13.93	1.33	0.33	13.22, 14.64	14.08	12.85, 14.94	11.00	16.08	0
Age puberty onset (years)¥									
All (n=45)	12.49	1.06	0.16	12.17, 12.81	13.00	12.00, 13.00	9	15	13
6 mth C (n=35)	12.66	0.97	0.16	12.32, 12.99	13.00	12.00, 13.00	11	15	10
6 mth NC (n=10)	11.90	1.20	0.38	11.04, 12.76	12.00	11.75, 13.00	9	13	3
12 mth C (n=34)	12.65	0.99	0.17	12.30, 12.99	13.00	12.00, 13.00	11	15	8
12 mth NC (n=11)	12.00	1.18	0.36	11.21, 12.79	12.00	12.00, 13.00	9	13	5
Income, postcode (weekly gross £)									
All (n=58)	748.79	231.97	30.46	687.80, 809.79	700.00	587.5, 860	430	1510	0
6 mth C (n=45)	736.00	195.34	29.12	677.31, 794.69	700.00	595, 850	430	1360	0
6 mth NC (n=13)	793.08	336.09	93.21	589.98, 996.17	760.00	555, 900	440	1510	0
12 mth C (n=42)	749.52	194.95	30.08	688.77, 810.27	735.00	610, 860	430	1360	0
12 mth NC (n=16)	746.88	317.17	79.29	577.87, 915.88	670.00	520, 850	440	1510	0

* C = completer; NC = non-completer; ¥ = of those who reported reaching puberty in table 7.3.

Table 10.3 continued

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
Standing height (cm)									
All (n=58)	162.66	11.00	1.44	159.76, 165.55	164.50	156.00, 170.25	127.00	187.00	0
6 mth C* (n=45)	164.00	10.02	1.49	160.99, 167.01	165.00	158.50, 171.00	140.00	187.00	0
6 mth NC* (n=13)	158.00	13.26	3.68	149.99, 166.01	160.00	151.50, 167.50	127.00	178.00	0
12 mth C (n=42)	164.40	10.19	1.57	161.23, 167.58	165.00	159.75, 171.00	140.00	187.00	0
12 mth NC (n=16)	158.06	12.02	3.01	151.65, 164.47	159.00	154.00, 166.50	127.00	178.00	0
Weight (kg)									
All (n=58)	52.74	11.86	1.56	49.62, 55.86	54.00	44.50, 61.00	28.00	75.00	0
6 mth C (n=45)	52.62	12.31	1.84	48.92, 56.32	54.00	44.00, 61.00	28.00	75.00	0
6 mth NC (n=13)	53.15	10.57	2.93	46.77, 59.54	51.00	45.00, 61.50	37.00	75.00	0
12 mth C (n=42)	52.74	12.32	1.90	48.90, 56.58	54.00	45.00, 61.00	28.00	75.00	0
12 mth NC (n=16)	52.75	10.93	2.73	46.92, 58.58	50.50	43.00, 61.75	37.00	75.00	0
Body mass index (BMI)									
All (n=58)	19.86	4.18	0.55	18.76, 20.96	19.57	17.22, 21.21	13.45	40.30	0
6 mth C (n=45)	19.34	3.35	0.50	18.34, 20.35	18.86	17.16, 21.26	13.45	27.48	0
6 mth NC (n=13)	21.64	6.12	1.70	17.95, 25.34	20.17	18.48, 21.24	16.67	40.30	0
12 mth C (n=42)	19.29	3.31	0.51	18.25, 20.32	19.06	17.17, 20.94	13.45	27.48	0
12 mth NC (n=16)	21.36	5.75	1.44	18.30, 24.43	20.00	17.76, 22.27	16.44	40.30	0

* C = completer; NC = non-completer

Differences in baseline spinal deformity and bracing status between participants who completed all follow-ups and non-completers are presented in Table 10.4 and Table 10.5.

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Non-completers were more likely at baseline to wear a brace (36% NC v 12-13% C), have a double curve (50 and 60% for 6 and 12 month NC v 44 and 41% for C respectively), with the primary curve convex to the left (58 and 47% NC v 30 and 33% C at 6 and 12 months respectively) and the apex located in the lumbar spine (54 and 44% NC v 22 and 24% C). A greater proportion of non-completers had baseline Risser signs of 0-2 (62.5% and 72.8% NC v 25.1 and 16% C) indicating lower levels of skeletal maturity, which is consistent with their younger age on average at initial presentation. There was no relevant difference in mean baseline Cobb angles between completers and 6 and 12 month non-completers.

Caution should be taken when interpreting these results. Due to low numbers of participants in some categories, small differences in actual numbers can result in large proportional differences.

Table 10.4 Participant baseline Cobb angle (main curve) by responder type

	mean	sd	SE	95% CI	median	IQR	min	max	missing (n)
All (n=57)	34.02	10.00	1.32	31.36, 36.67	34.00	27.00, 41.00	14.00	50.00	1 (1.7)
6 mth C* (n=45)	34.07	10.05	1.50	31.05, 37.09	34.00	26.00, 42.50	15.00	35.00	0
6 mth NC* (n=12)	33.83	10.26	2.96	27.32, 40.35	34.00	27.00, 40.00	14.00	50.00	1 (7.7)
12 mth C (n=42)	34.21	10.28	1.59	31.01, 37.42	34.50	34.50, 43.00	15.00	50.00	0
12 mth NC (n=15)	33.47	9.50	2.45	28.21, 38.73	32.00	27.00, 40.00	14.00	50.00	1 (6.3)

* C = completer; NC = non-completer

Table 10.5 Participant baseline brace use & spinal deformity characteristics by responder type

	Category	All n (%)	6 months C n (%)	6 months NC n (%)	12 months C n (%)	12 months NC n (%)
Brace	Yes	10 (17.9)	6 (13.3)	4 (36.4)	5 (11.9)	5 (35.7)
	No	46 (82.1)	39 (86.7)	7 (63.6)	37 (88.1)	9 (64.3)
	subtotal	56	45	11	42	14
	missing	2	0	2	0	2
Curve type	Single	30 (52.6)	24 (53.3)	6 (50.0)	24 (57.1)	6 (40.0)
	Double	26 (45.6)	20 (44.4)	6 (50.0)	17 (40.5)	9 (60.0)
	Triple	1 (1.8)	1 (2.2)	0	1 (2.4)	0
	subtotal	57	45	12	42	15
	missing	1	0	1	0	1
Curve direction*	Right	35 (63.6)	30 (69.8)	5 (41.7)	27 (67.5)	8 (53.3)
	Left	20 (36.4)	13 (30.2)	7 (58.3)	13 (32.5)	7 (46.7)
	subtotal	55	43	12	40	15
	missing	3	2	1	2	1
Curve location*	thoracic	36 (62.1)	31 (68.9)	5 (38.5)	28 (66.7)	8 (50.0)
	thoracolumbar	2 (3.4)	2 (4.4)	0	2 (4.8)	0
	lumbar	17 (29.3)	10 (22.2)	7 (53.8)	10 (23.8)	7 (43.8)
	unknown	2 (3.4)	2 (4.4)	1 (7.7)	2 (4.8)	1 (6.3)
	subtotal	57	45	12	42	16
	missing	1	0	0	0	0
Risser sign	0 - 0%	7 (19.4)	5 (17.9)	2 (25.0)	3 (12.0)	4 (36.4)
	1 - 25%	3 (8.3)	1 (3.6)	2 (25.0)	1 (4.0)	2 (18.2)
	2 - 50%	2 (5.6)	1 (3.6)	1 (12.5)	0	2 (18.2)
	3 - 75%	7 (19.4)	6 (21.4)	1 (12.5)	7 (28.0)	0
	4 - 100%	11 (30.6)	10 (35.7)	1 (12.5)	9 (36.0)	2 (18.2)
	5 - skeletal maturity	6 (16.7)	5 (17.9)	1 (12.5)	5 (20.0)	1 (9.1)
	subtotal	36	28	8	25	11
	missing	22	17	5	17	5

* of main curve; C = completer; NC = non-completer

10.1.3 Data analysis - participants available

As described previously, a total of 58 participants were recruited at baseline. Of these, 42 were followed up at 12 months and are described in subsequent sections as 12 month completers. Descriptive statistics were calculated and plots drawn separately for 12 mth completers (C) as well as for all those participants for whom information was available at each individual time-point (all responders; n= 58 and 45 for baseline and 6 months respectively).

10.2 Spinal deformity

Spinal deformity was assessed by variables calculated from x-ray. Due to the small number of participants who underwent surface topography imaging, and the lack of any significant relationships between ISIS-2 and body schema measures (as described in Chapter 7), analyses of surface topography were not conducted as part of this study.

Descriptive statistics for Cobb angle along with coronal and sagittal balance are provided in

Table 10.6 to Table 10.8 and illustrated in Figure 10.2 to Figure 10.10. Details of these measures are provided in Appendix 6. Results of statistical analyses are summarised in Table 10.9. Unless otherwise stated, a two (trial arm) by three (time-point) mixed repeated measures ANOVA was conducted to compare the dependent (outcome) variable in each condition.

10.2.1 Cobb angle

On average, Cobb angle increased by 3.5 degrees between baseline and 12 months (Table 10.6). The Cobb angle at baseline and 6 months for participants who completed the 12 month time-point (C) was very similar to all participants for whom information was available at each of these time-points (All).

Statistical analysis resulted in a statistically significant main effect of time-point ($F(1.31, 41.76) = 4.22$; $p=0.036$; $\eta^2=.117$) (Table 10.9). Contrasts revealed that Cobb angle at 12 months was greater than at baseline ($F(1, 32) = 5.284$; $p=.028$; $\eta^2=.142$). However, the difference was not statistically significant after pairwise comparison with Bonferroni correction (mean difference=2.971; SE 1.17; 95% CI -.294, 6.235, p=0.085).

There was no statistically significant interaction between time-point and arm.

Table 10.6 Cobb angle - descriptive statistics

time point	status *	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
baseline	All (n=57)	34.02	10.00	1.32	31.36, 36.67	34.00	27, 41	14.00	50.00	1 (1.7)
	C (n=42)	34.21	10.28	1.59	31.01, 37.42	34.50	24.5, 43	15.00	50.00	0
6 months	All (n=39)	34.46	10.51	1.68	31.06, 37.87	35.00	28, 44	14.00	55.00	19 (32.8)
	C (n=38)	34.82	10.41	1.69	31.39, 38.24	35.00	28, 44.25	14.00	55.00	4 (9.5)
12 months	All/C (n=35)	37.54	9.84	1.66	34.16, 40.92	37.00	32, 46	15.00	55.00	23 (39.7) / 7 (16.7)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.2.2 Coronal balance

There was virtually no difference in coronal balance between time-points or between 12 month completers and all responders at baseline and 6 months (Table 10.7).

There was no statistically significant main effect of time-point ($F(2, 52) = .61$; $p=0.549$; $\eta^2=.023$), nor was there a statistically significant interaction between time-point and trial arm assumed (Table 10.9).

Table 10.7 X-ray coronal balance - descriptive statistics

time point	status *	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
baseline	All (n=55)	17.38	12.95	1.75	13.88, 20.88	15	8, 27	0	47	3 (5.2)
	C (n=40)	17.53	14.11	2.23	13.01, 22.04	14	7, 28	0	47	2 (4.76)
6 months	All (n=35)	17.26	11.87	2.01	13.18, 21.33	17	10, 24	0	45	23 (39.7)
	C (n=34)	17.29	12.05	2.07	13.09, 21.50	17	9.8, 24	0	45	8 (19.1)
12 months	All/C (n=34)	17.47	11.95	2.05	13.30, 21.64	17	9.5, 26.3	0	42	24 (41.4) / 8 (19.1)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.2.3 Sagittal balance

Measures of sagittal balance were generally poorly completed with sizeable numbers of x-rays performed without this variable being calculated. Therefore, the results need to be viewed with caution.

On average, there were small differences in mean sagittal balance between time-points (Table 10.8). No statistically significant main effect of time-point was observed (F(2, 22) =0.77, p=0.476; η^2=.065), nor was there a statistically significant interaction between time-point and trial arm (Table 10.9).

Table 10.8 X-ray sagittal balance - descriptive statistics

time point	status*	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
Sagittal balance (mm)										
baseline	All (n=42)	37.76	28.79	4.44	28.79, 46.73	29.00	16.8, 54	0	97	16 (27.6)
	C (n=29)	32.38	24.18	4.49	23.18, 41.58	26.00	16.5, 47	0	97	13 (30.95)
6 months	All (n=22)	28.55	17.81	3.80	20.65, 36.44	24.50	16.8, 39.8	0	78	36 (62.1)
	C (n=21)	29.00	18.11	3.95	20.75, 37.25	25.00	16.5, 41.5	0	78	21 (50.0)
12 months	All/C (n=14)	32.07	20.93	5.59	19.99, 44.46	28.50	16.8, 46.8	0	78	44 (75.9) / 28 (66.7)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.9 Summary of statistical analyses - x-ray

analysis	n	interaction	type (ε)	F	df_M	df_R	p-value	effect size, η^2
Cobb angle (degrees)	34	timepoint	GG (0.652)	4.22	1.31	41.76	0.036*	0.117
		timepoint x arm		0.54			0.51	.017
Coronal balance (mm)	28	timepoint	SA (0.884)	0.61	2	52	0.549	.023
		timepoint x arm		1.00			0.376	.037
Sagittal balance (mm)	13	timepoint	SA (0.883)	0.77	2	22	0.476	.065
		timepoint x arm		0.32			0.733	.028

* = statistically significant; GG = Greenhouse Guisser estimate of sphericity; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η2=partial eta squared

Figure 10.2 Cobb angle - histogram

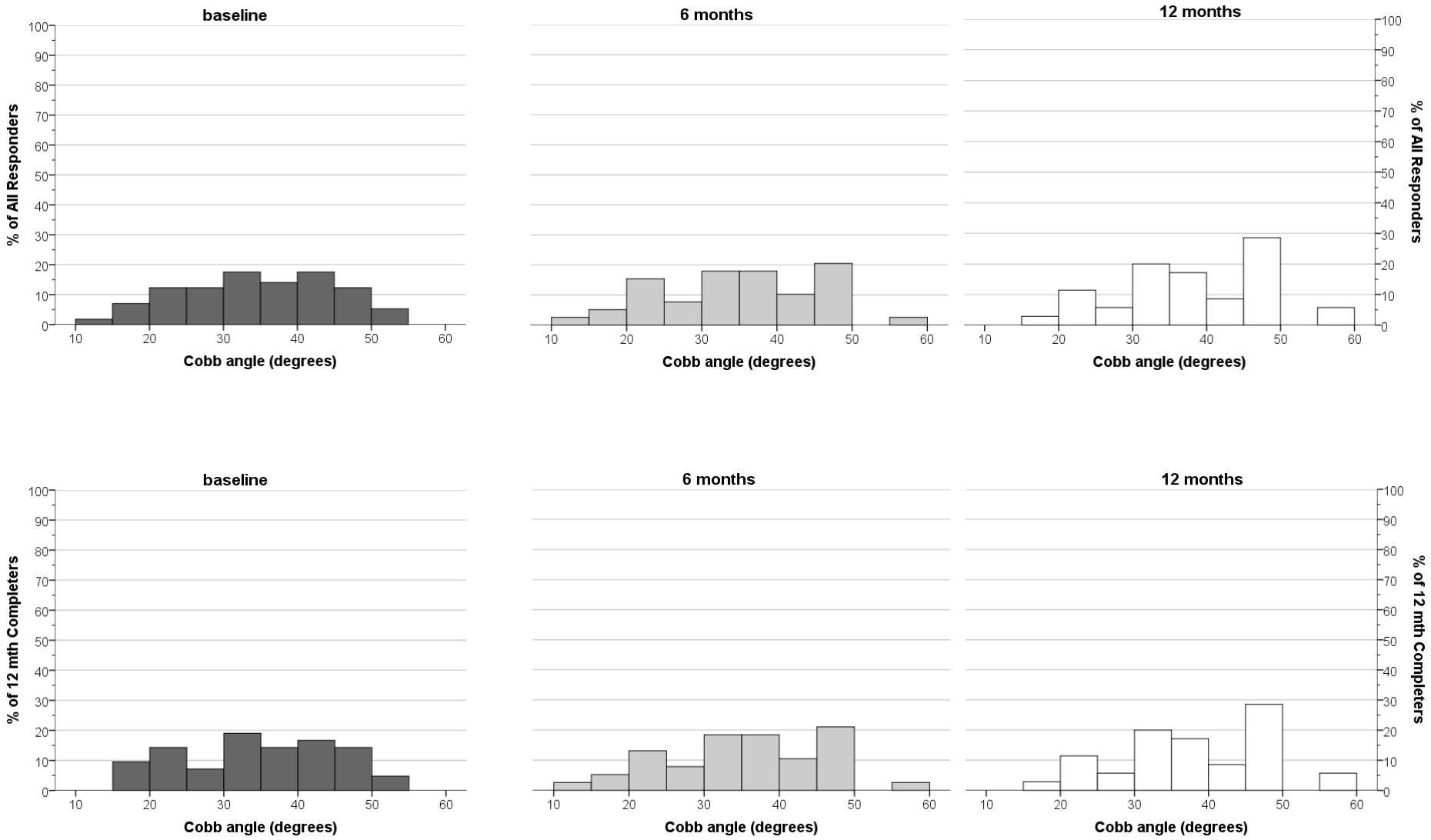


Figure 10.3 Cobb angle - boxplots

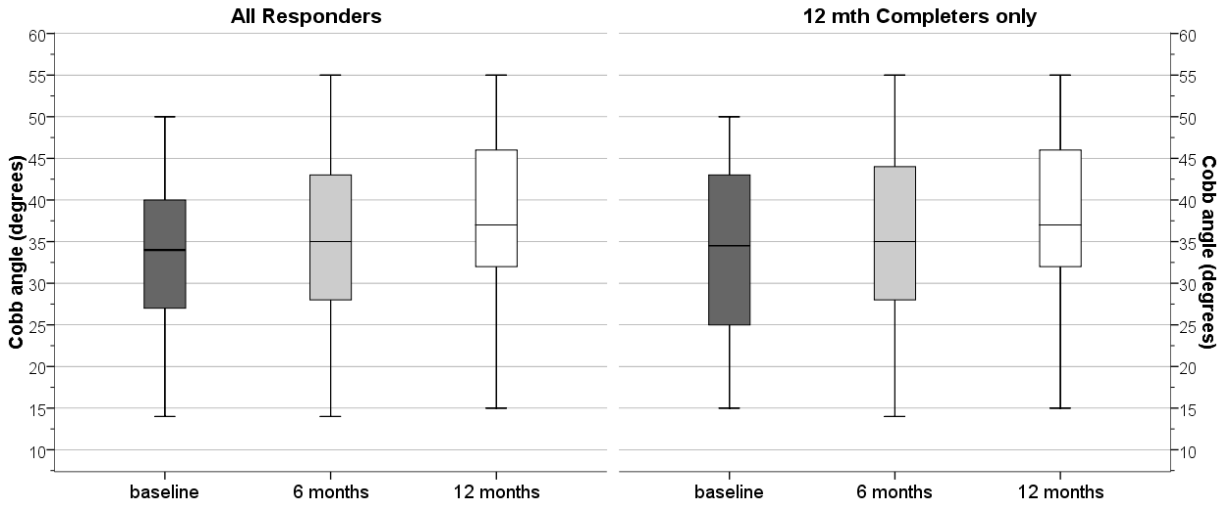


Figure 10.4 Cobb angle - means (95% CI)

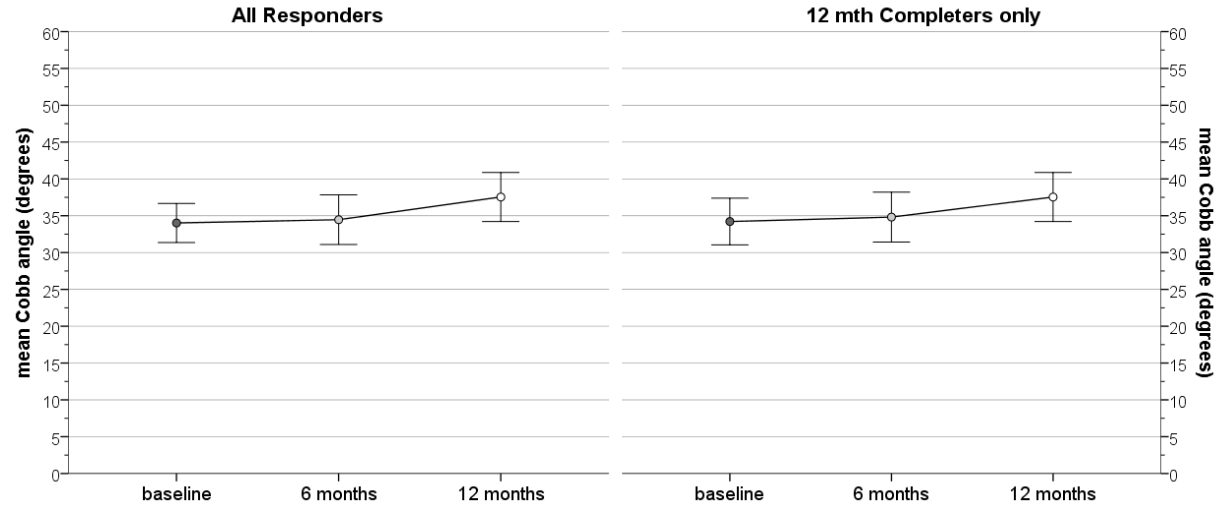


Figure 10.5 X-ray coronal balance - histograms

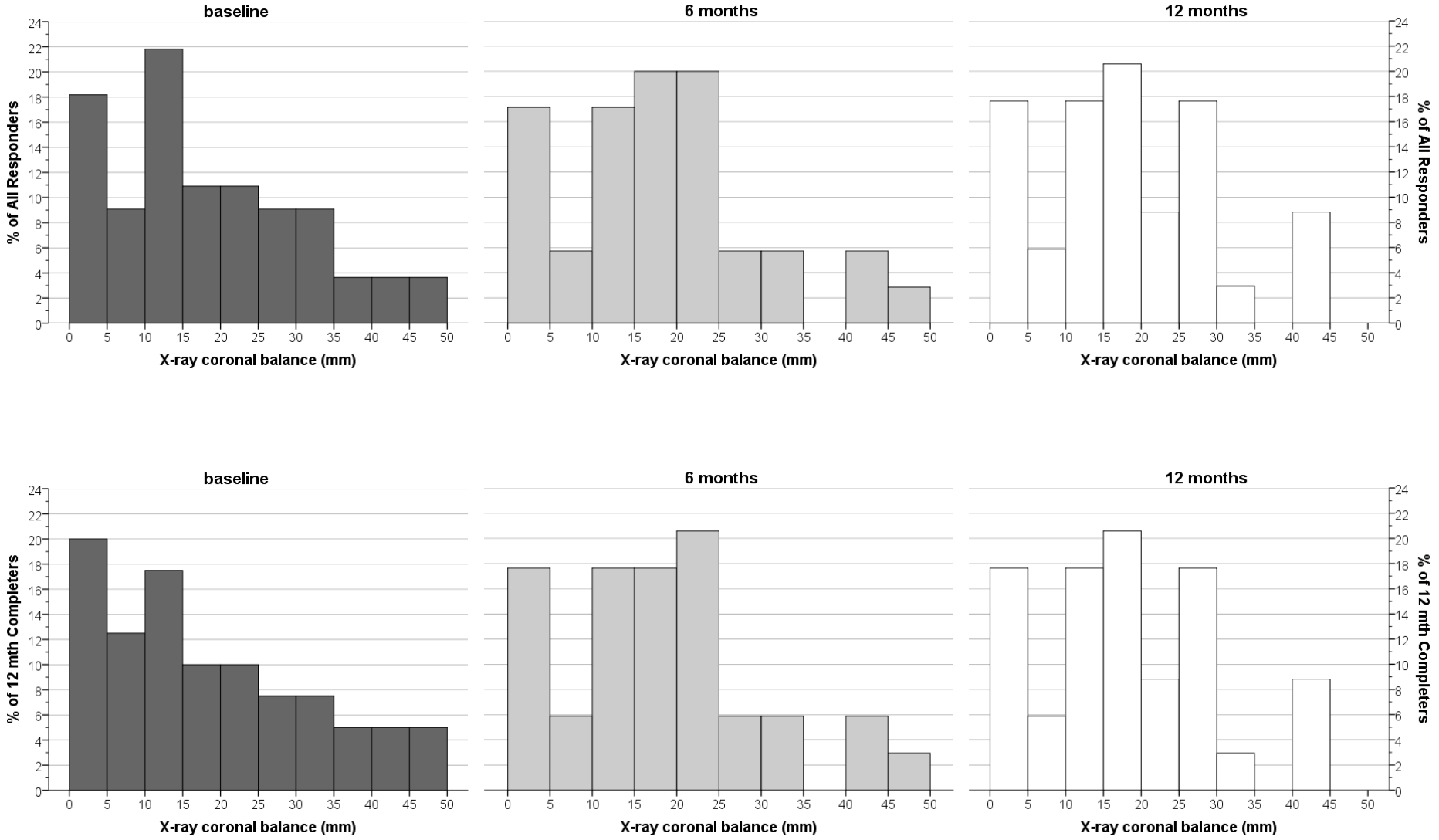


Figure 10.6 X-ray coronal balance - boxplots

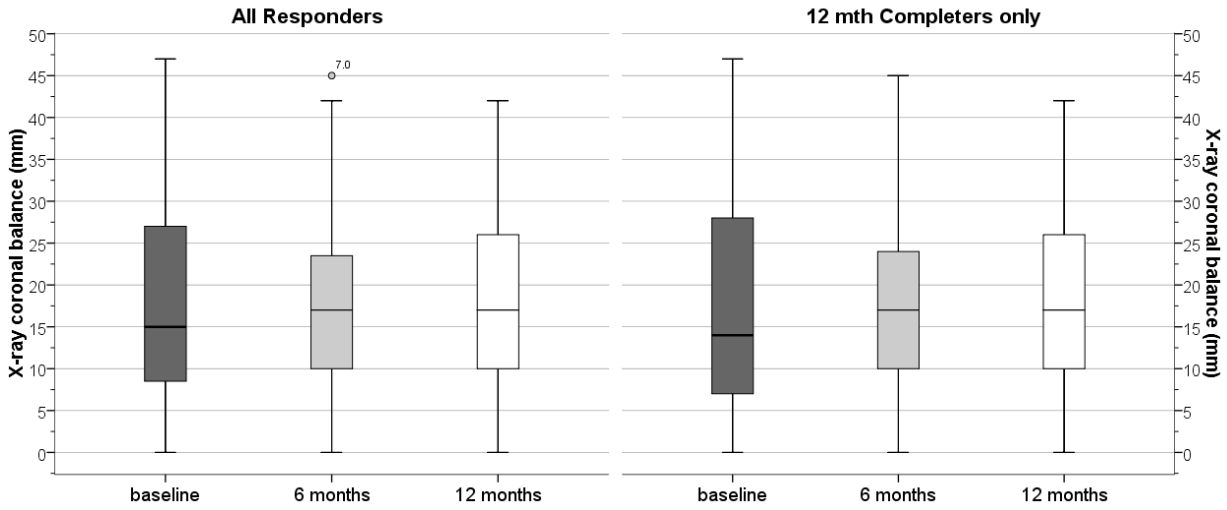


Figure 10.7 X-ray coronal balance - means (95% CI)

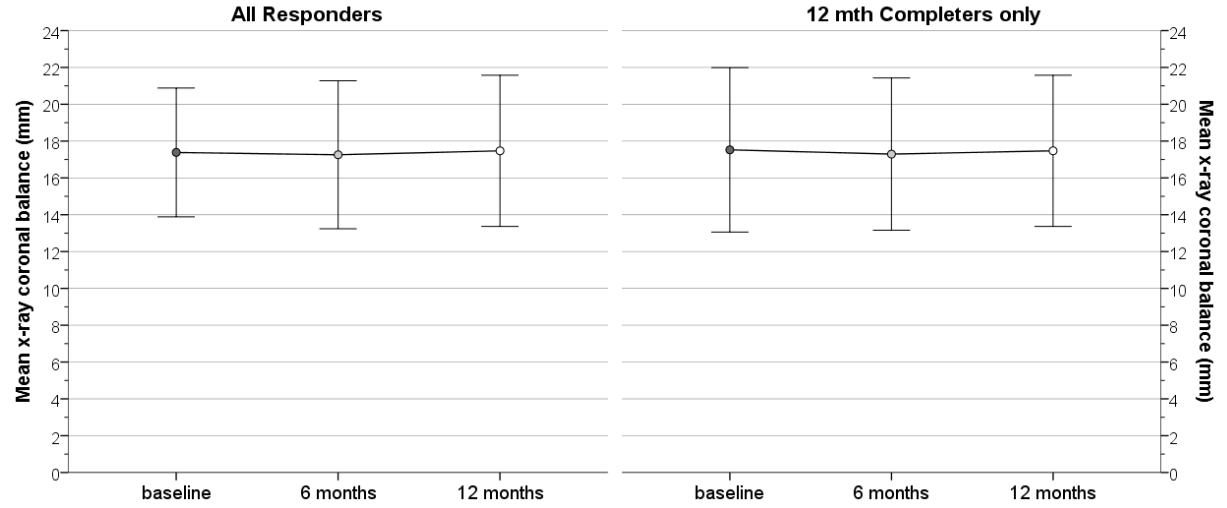


Figure 10.8 X-ray sagittal balance - histograms

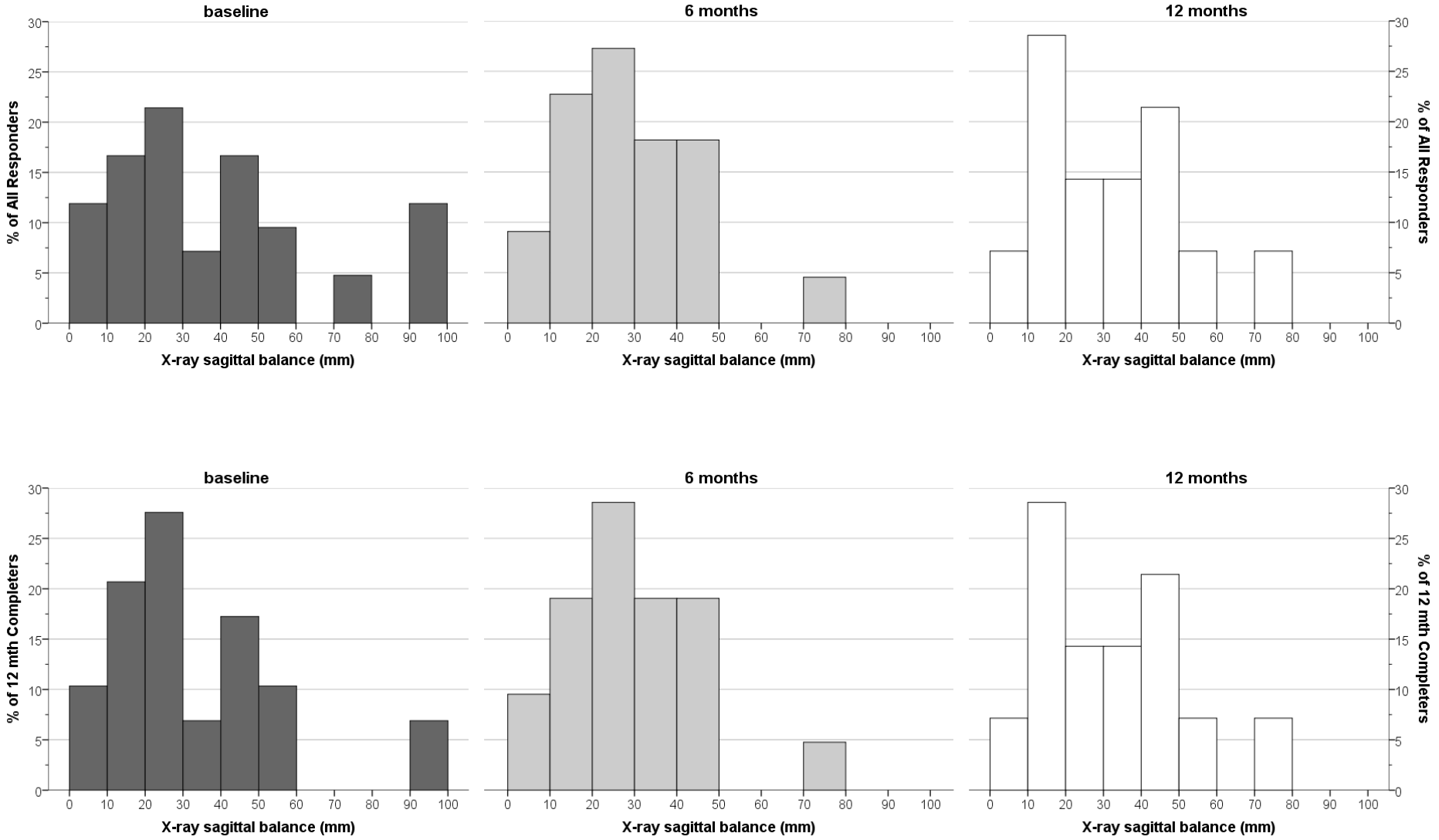


Figure 10.9 X-ray sagittal balance - boxplots

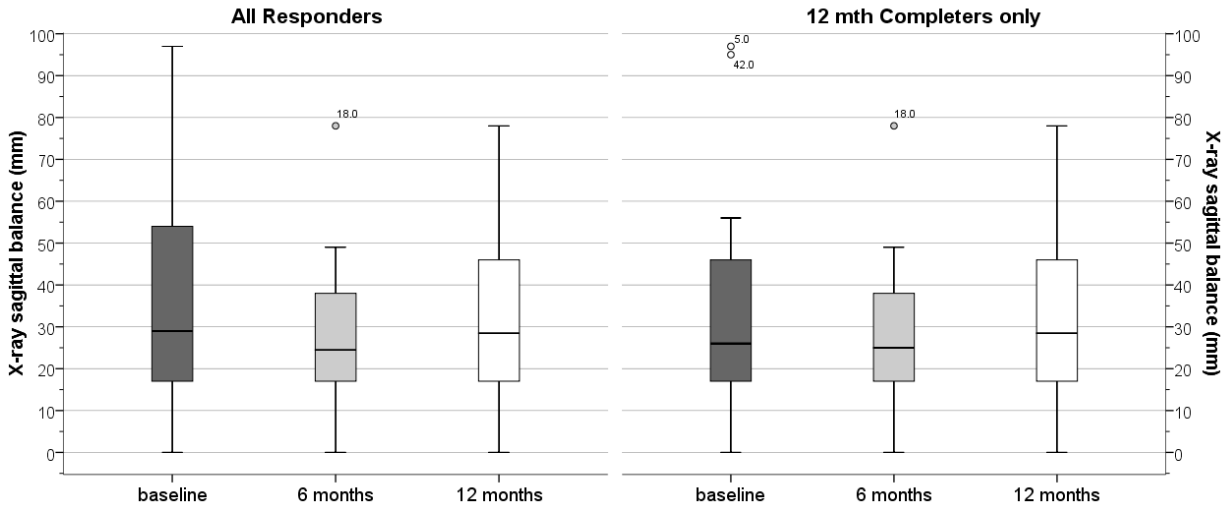
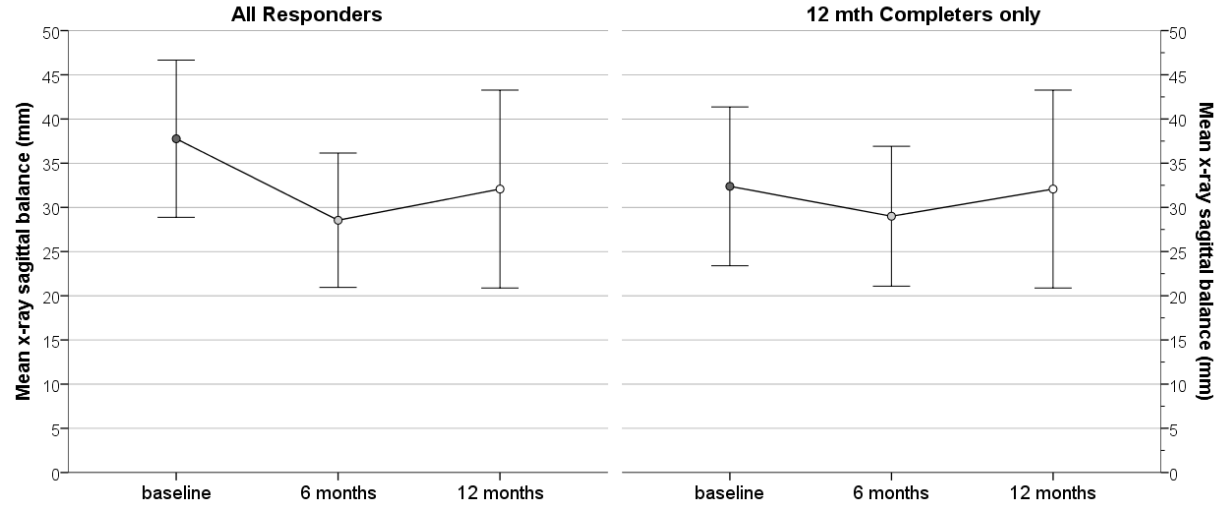


Figure 10.10 X-ray sagittal balance - means (95% CI)



10.3 Self-report Measures

10.3.1 Spinal Appearance Questionnaire (SAQ)

Descriptive statistics are presented in Table 10.10 to Table 10.12 and illustrated in Figure 10.12 to Figure 10.23. A summary of statistical analyses is presented in Table 10.13.

10.3.1.1 Appearance scale

There was virtually no difference in appearance score between time-points or between 12 month completers and all responders at baseline and 6 months (Table 10.10).

There was no statistically significant main effect of time-point (F(1.72, 58.42) =0.09; p=0.887; η^2=.003), nor was there a statistically significant interaction between time-point and trial arm condition (Table 10.13).

Table 10.10 SAQ appearance score - descriptive statistics

SAQ appearance (10 best - 50 worst)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=56)	22.61	5.91	0.79	21.02, 24.19	22.00	18.00, 27.75	11.00	38.00	2 (3.4)
	C (n=41)	23.10	6.42	1.00	21.07, 25.12	23.00	18.00, 28.00	11.00	38.00	1 (2.4)
6 months	All (n=44)	22.50	6.35	0.96	20.57, 24.43	23.00	18.25, 26.00	11.00	38.00	14 (24.1)
	C (n=40)	22.28	6.11	0.97	20.32, 24.23	23.00	18.25, 26.00	11.00	36.00	2 (4.8)
12 months	All/C (n=38)	22.56	7.25	1.18	20.18, 24.94	22.00	16.75, 27.25	11.25	45.00	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.3.1.2 Expectations scale

Overall, there was little difference in expectations score between time-points (Table 10.11).

There was no statistically significant main effect of time-point (F(2, 70) =0.61; p=0.554; η^2=.017) (Table 10.13), nor was there a statistically significant between-subjects effect for trial arm (F(1, 35) =1.148; p=0.291; η^2=.032).

However, there was a statistically significant interaction between time-point and trial arm ($F(2, 70) = 9.39$; $p<0.001$; $\eta^2=.211$). This indicates that trial arm allocation had different effects on expectation score depending on time-point. Between subject contrasts revealed significant interactions when comparing experimental to control arm intervention for both baseline ($F(1, 35) = 13.94$; $p=0.001$; $\eta^2=.285$) and 6 month time-points ($F(1, 35) = 9.91$; $p=.003$; $\eta^2=.221$) compared to 12 months. These results reflect the higher (i.e. worse) scores for participants in the experimental intervention arm (compared to control participants) at baseline and 6 months compared to 12 months (Table 10.11

Figure 10.11).

Table 10.11 SAQ expectations score - descriptive statistics

SAQ expectations (4 best - 20 worst)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	13.10	4.71	0.62	11.85, 14.35	13.00	9.50, 17.00	4.00	20.00	1 (1.7)
	C (n=42)	13.66	4.73	0.73	12.18, 15.13	14.00	10.50, 17.25	4.00	20.00	0
6 months	All (n=44)	12.98	5.14	0.78	11.41, 14.54	14.00	9.00, 17.75	4.00	20.00	14 (24.1)
	C (n=40)	13.08	5.13	0.81	11.44, 14.71	14.00	9.00, 18.00	4.00	20.00	2 (4.8)
12 months	All/C (n=38)	12.95	5.27	0.86	11.21, 14.68	13.00	8.50, 17.25	4.00	20.00	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.3.1.3 Total score

Similar results were calculated for the total SAQ score with little difference in overall mean scores (Table 10.12) and no statistically significant effects of time-point ($F(1.70, 57.9) =0.22$; $p=0.766$; $\eta^2=.006$), nor trial arm ($F(1, 34) =1.81$; $p=0.188$; $\eta^2=.050$) (Table 10.13). The statistically significant interaction of time-point and trial arm ($F(1.70, 57.9) =5.38$; $p=0.01$; $\eta^2=.137$) highlighted that trial arm allocation had different effects on total SAQ score depending on time-point. Between subject contrasts revealed significant interactions when comparing experimental to control arm intervention for both baseline v 12 months ($F(1, 34) =7.24$; $p=0.011$; $\eta^2=.176$) and 6 month v 12 month time-points ($F(1, 34) =5.57$; $p=.024$; $\eta^2=.141$). These results reflect the higher (i.e. worse) scores for participants in the experimental intervention arm (compared to control participants) at baseline and 6 months compared to 12 months (Figure 10.11).

Table 10.12 SAQ total score - descriptive statistics

SAQ total (14 best - 70 worst)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**

baseline	All (n=56)	35.60	9.25	1.24	33.12, 38.08	36.00	28.00, 43.00	15.00	55.00	2 (3.4)
	C (n=41)	36.63	9.7	1.52	33.56, 39.69	37.00	30.00, 43.50	15.00	55.00	1 (2.4)
6 months	All (n=44)	35.48	9.85	1.49	32.48, 38.47	34.50	29.00, 43.75	15.00	53.00	14 (24.1)
	C (n=40)	35.35	9.97	1.58	32.16, 38.54	34.00	29.00, 43.75	15.00	53.00	2 (4.8)
12 months	All/C (n=38)	35.51	11.22	1.82	31.82, 39.20	35.50	26.25, 44.25	15.25	63.00	20 (34.5) / 4 (9.5)

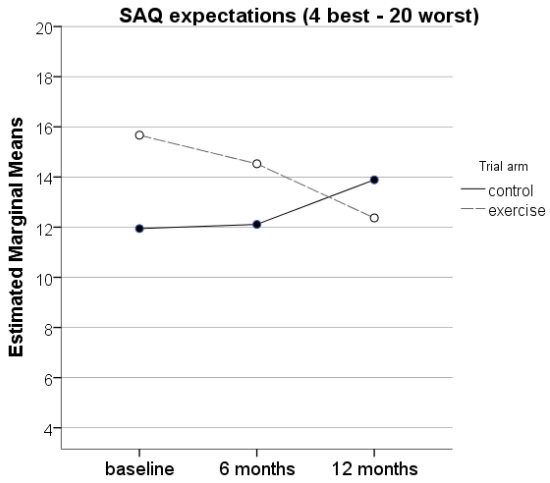
*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.13 Summary of statistical analyses - SAQ

analysis	n	interaction	type (ε)	F	df_M	df_R	p-value	effect size, η^2
Spinal Appearance Questionnaire (SAQ)								
Appearance	36	timepoint	HF (0.86)	0.09	1.718	58.42	0.887	0.003
		timepoint x arm		1.19			0.305	0.034
Expectations	37	timepoint	SA (0.93)	0.61	2	70	0.544	0.017
		timepoint x arm		9.39			<0.001*	0.211
Total score	36	timepoint	HF (0.85)	0.22	1.703	57.895	0.766	0.006
		timepoint x arm		5.38			0.01*	0.137

* = statistically significant; GG/HF = Greenhouse Guisser/Huynh-Feldt estimate of sphericity; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η2=partial eta squared

Figure 10.11 Interaction graphs - timepoint * arm



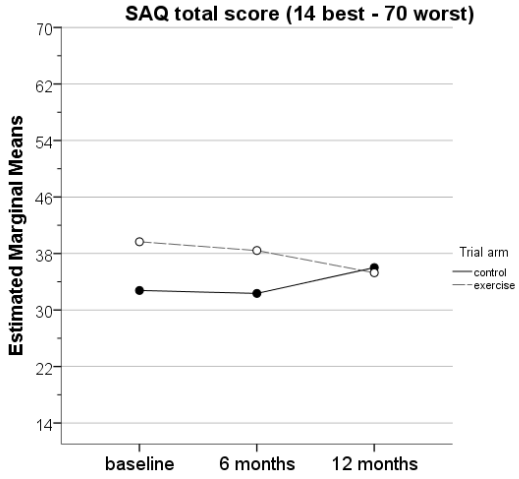


Figure 10.12 SAQ appearance score - All Responders histogram

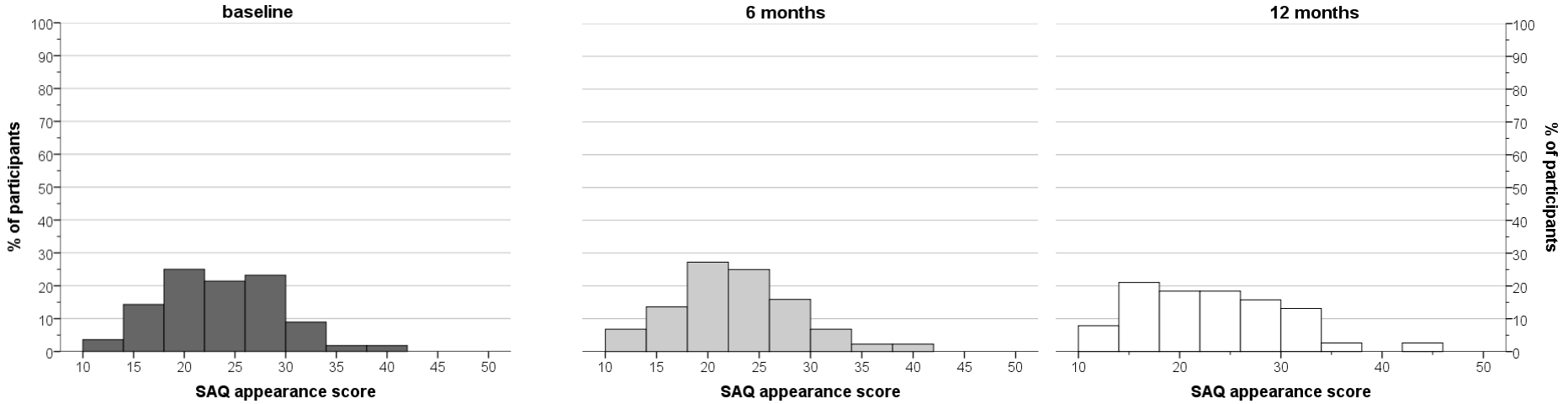


Figure 10.13 SAQ appearance score - 12 mth Completers only histogram

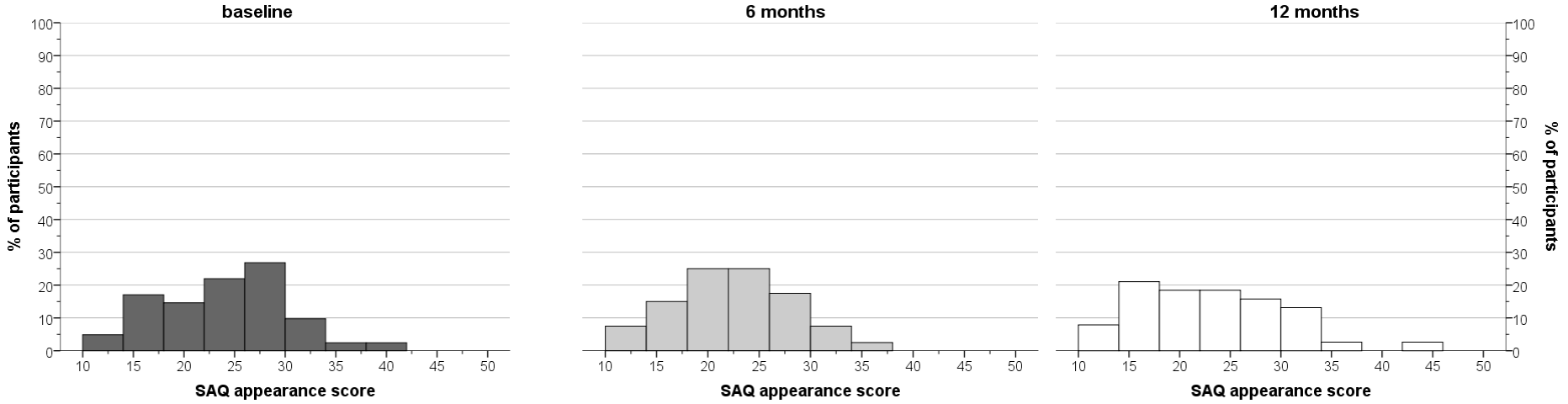


Figure 10.14 SAQ appearance score - boxplots

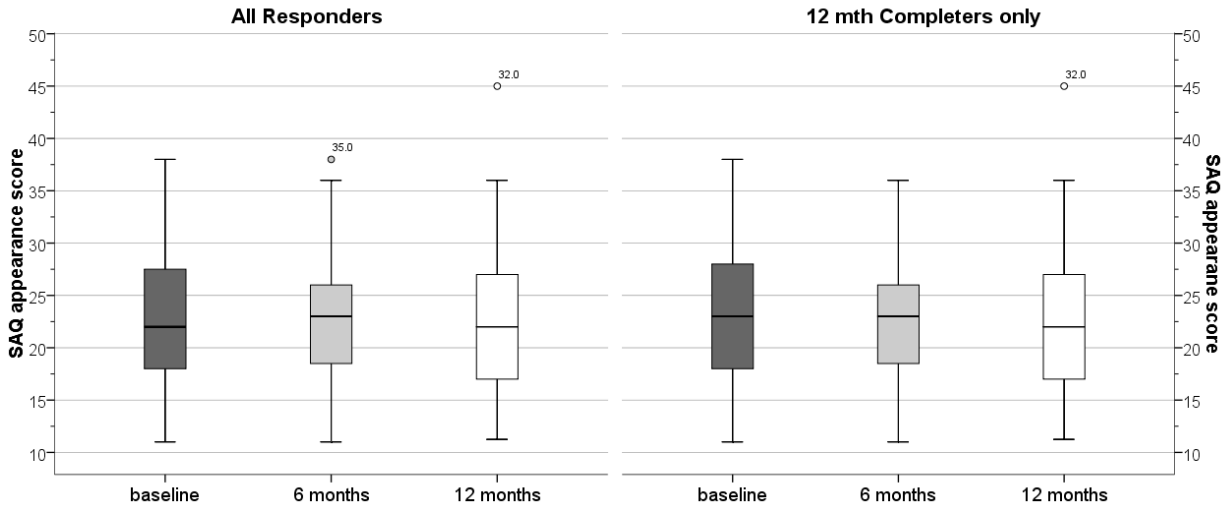


Figure 10.15 SAQ appearance score - means (95% CI)

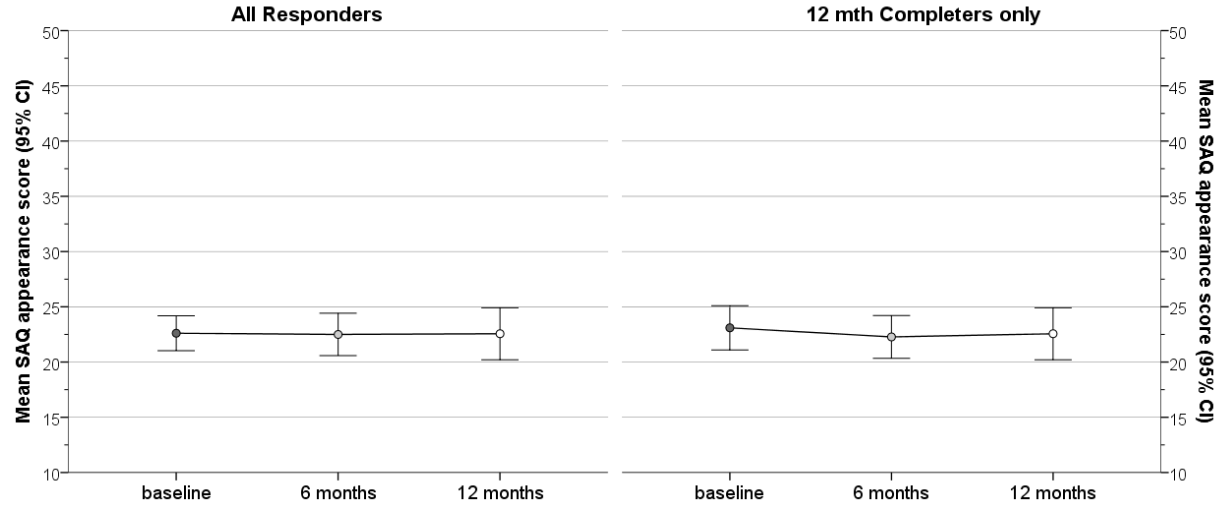


Figure 10.16 SAQ expectations score - All Responders histograms

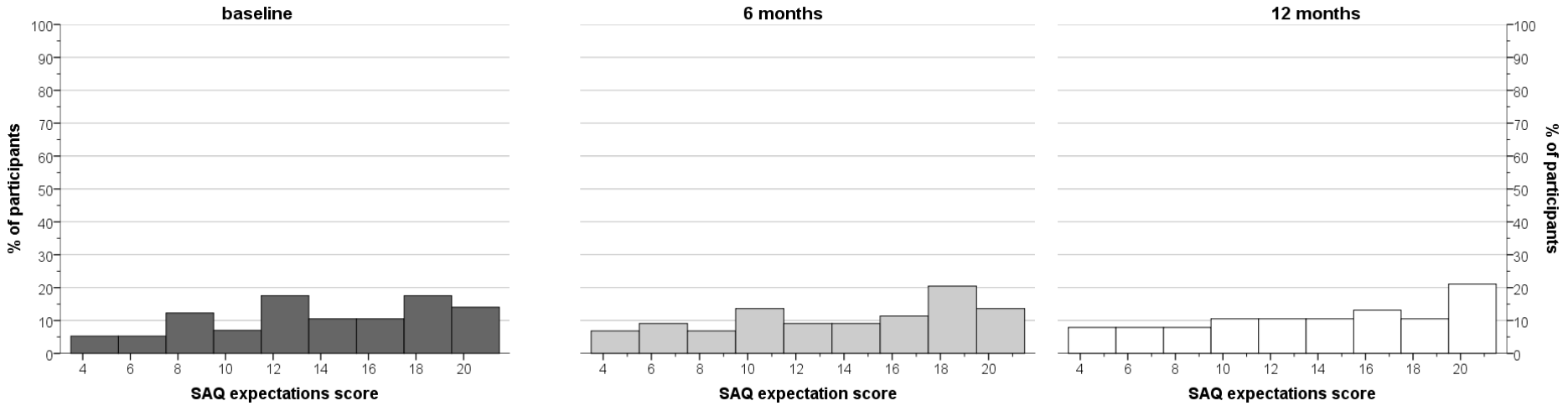


Figure 10.17 SAQ expectations score - 12 mth Completers only histograms

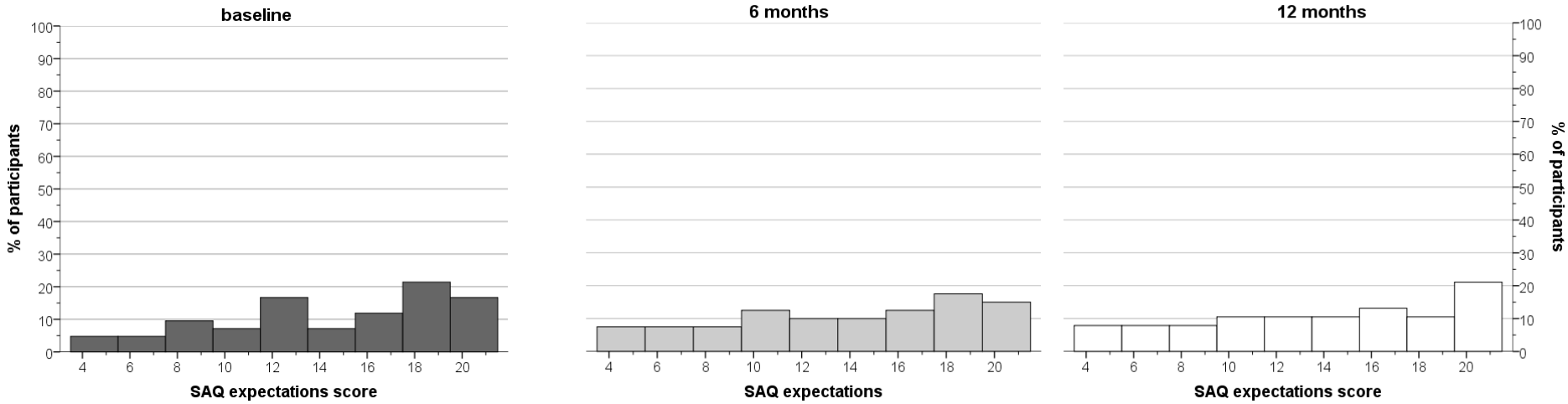


Figure 10.18 SAQ expectations score - boxplots

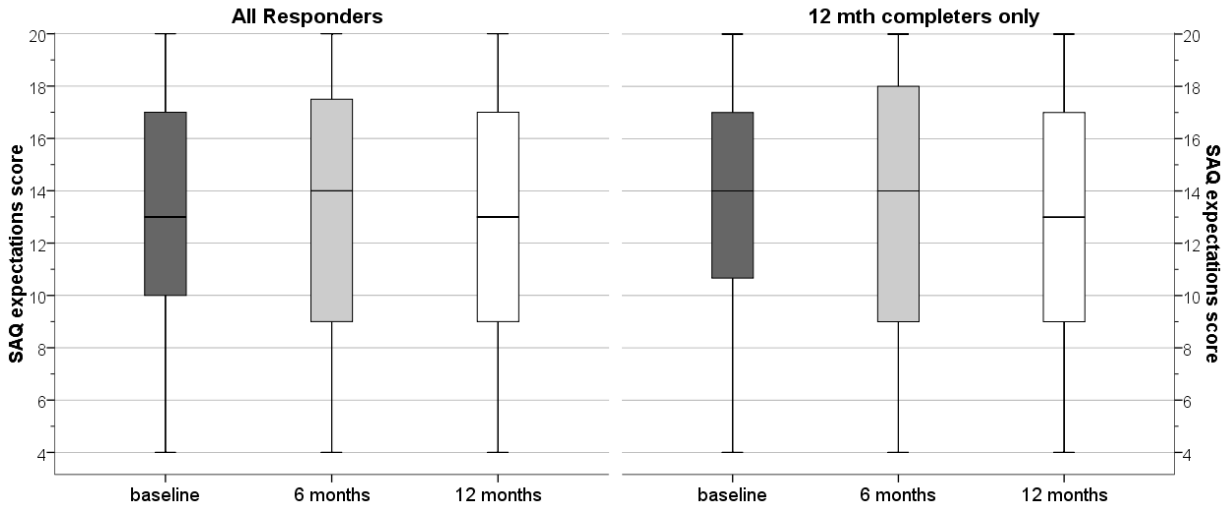


Figure 10.19 SAQ expectations score - means (95% CI)

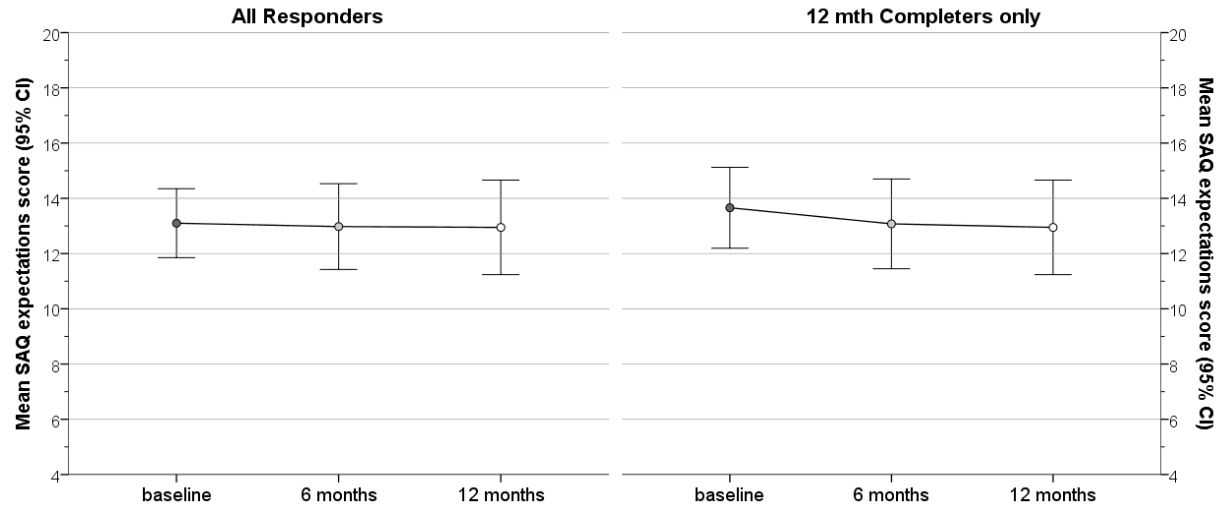


Figure 10.20 SAQ total score - All Responders histograms

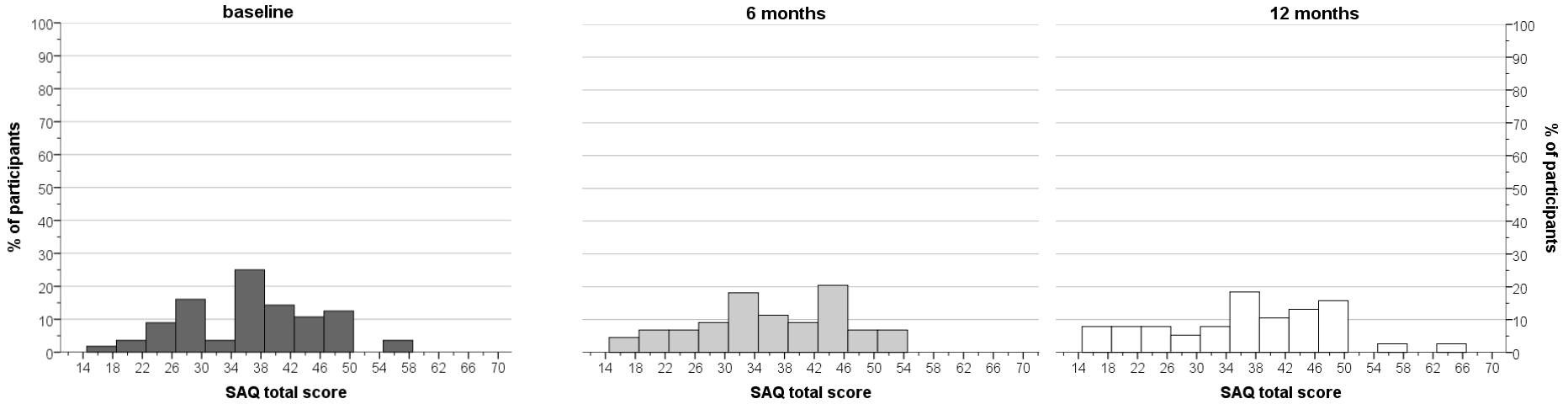


Figure 10.21 SAQ total score - 12 mth Completers only histograms

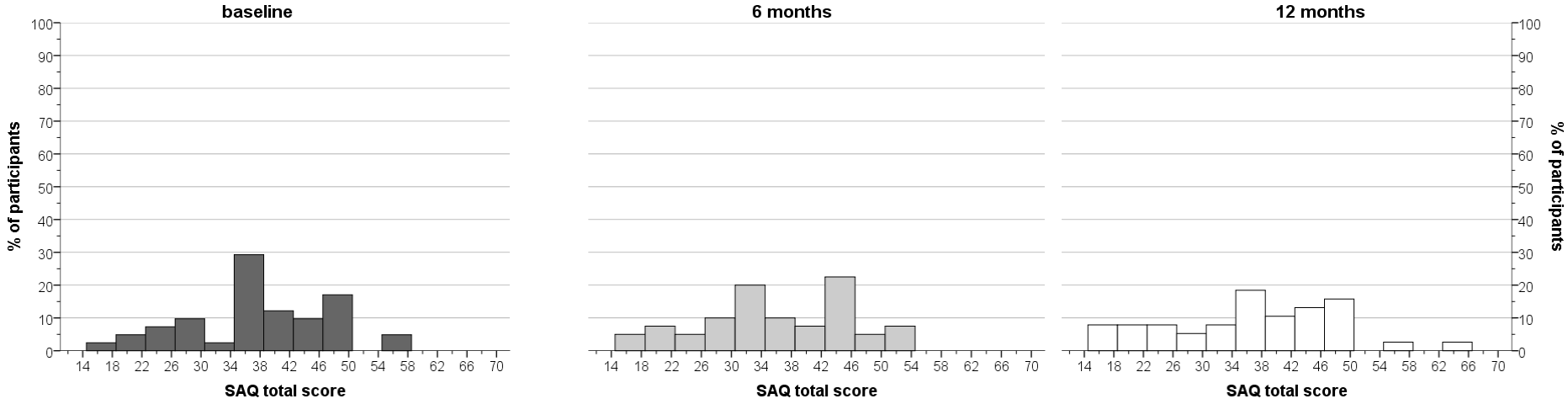


Figure 10.22 SAQ total score - boxplots

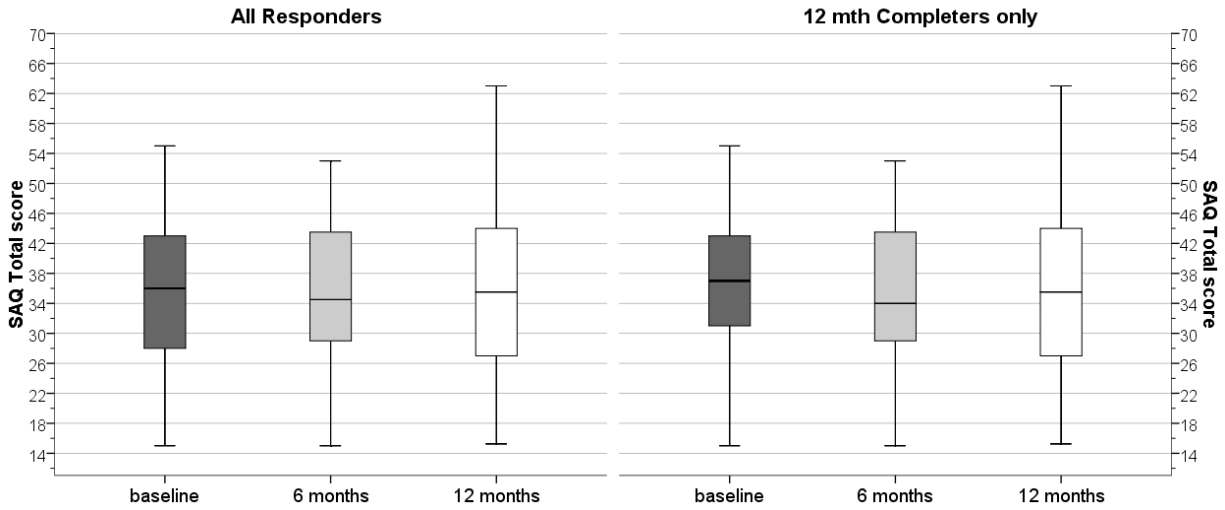
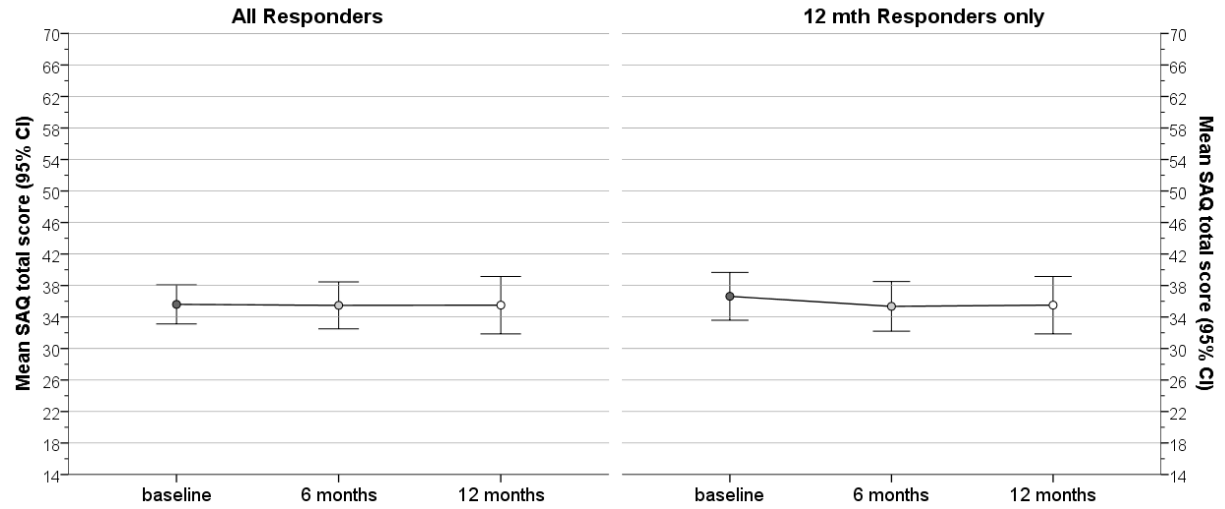


Figure 10.23 SAQ total score - means (95% CI)



10.3.2 Kinaesthetic & Proprioceptive Awareness Questionnaire (KPAQ)

Descriptive statistics are presented in Table 10.14 and illustrated in Figure 10.24 to Figure 10.27.

There were small differences in KPAQ score between time-points (Table 10.14). These differences were statistically significant ($F(2, 70) = 6.77$; $p = .002$; $\eta^2 = .162$) (Table 10.15). Contrasts revealed that KPAQ score at 12 months was greater than at baseline ($F(1, 35) = 12.48$; $p = .001$; $\eta^2 = .263$), and at 6 months ($F(1, 35) = 6.29$; $p = .017$; $\eta^2 = .152$). The difference between 6 and 12 months remained on the cusp of statistical significance after pairwise comparison with Bonferroni correction (mean difference=2.58; SE 1.03; 95% CI -.007, 5.168, p=0.051).

There was no statistically significant between-subject effect of trial arm ($F(1, 35) = .66$; $p = .422$; $\eta^2 = .019$). There was no statistically significant interaction between time-point and trial arm ($F(2, 70) = 1.81$; $p = .172$; $\eta^2 = .049$).

Table 10.14 KPAQ - descriptive statistics

KPAQ total (12 worst - 60 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	47.26	6.17	0.82	45.62, 48.90	48.00	41.50, 52.00	36.00	60.00	1 (1.7)
	C (n=42)	46.43	5.73	0.88	44.64, 48.21	47.50	41.75, 50.25	36.00	60.00	0
6 months	All (n=44)	46.99	5.28	0.80	45.39, 48.60	47.50	44.18, 50.00	32.00	57.00	14 (24.1)
	C (n=40)	47.47	5.29	0.84	45.78, 49.16	48.00	45.25, 50.75	32.00	57.00	2 (4.8)
12 months	All/C (n=38)	49.92	4.75	0.77	48.36, 51.48	49.50	47.00, 53.25	38.00	59.00	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.15 Summary of statistical analyses - KPAQ

analysis	**n**	**interaction**	**type (ε)**	**F**	**df_M**	**df_R**	**p-value**	**effect size, η^2**
KPAQ score	37	timepoint	SA (0.995)	6.77	2	70	0.002*	0.162
		timepoint x arm		1.81			0.172	0.049

* = statistically significant; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

Figure 10.24 KPAQ score - All Responders histograms

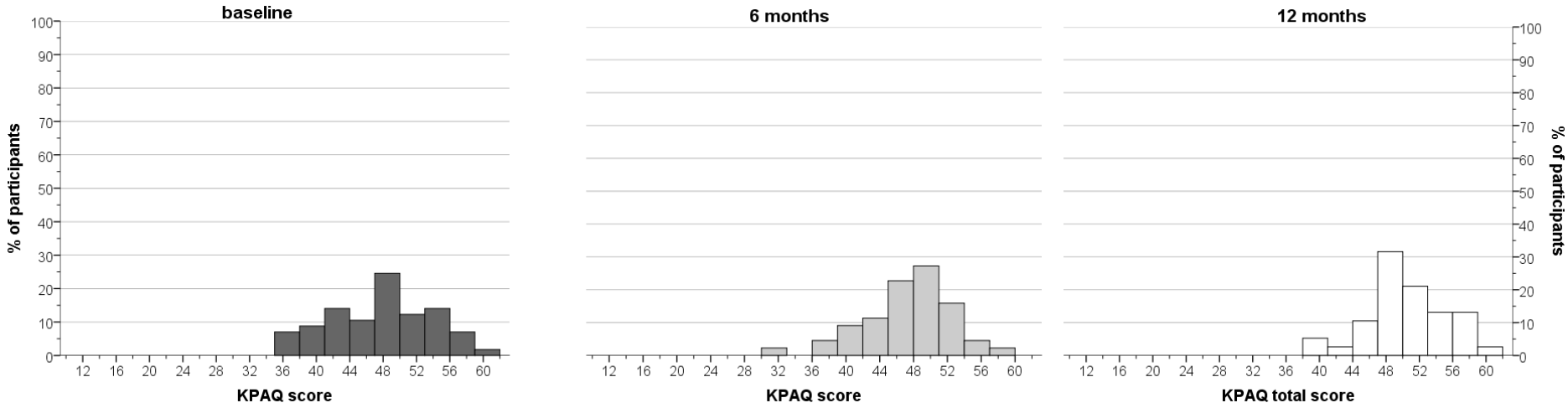


Figure 10.25 KPAQ score - 12 mth Completers only histograms

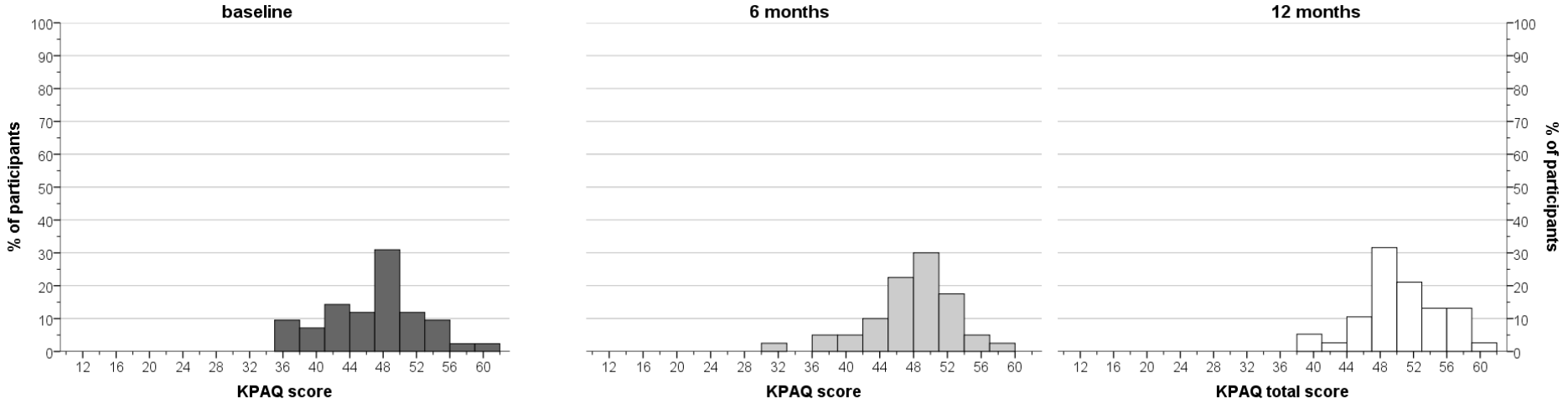


Figure 10.26 KPAQ - boxplots

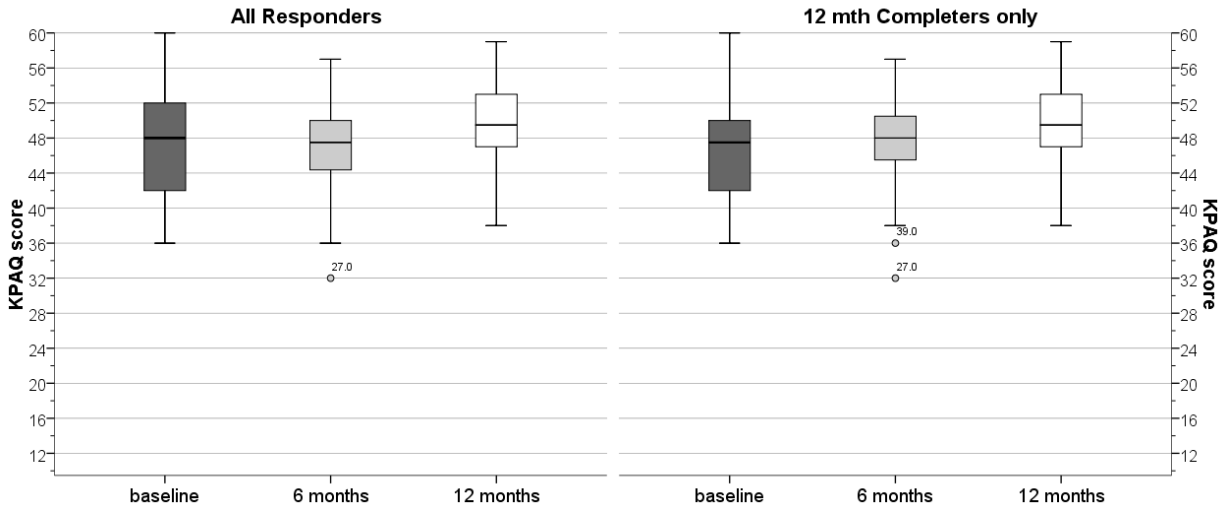
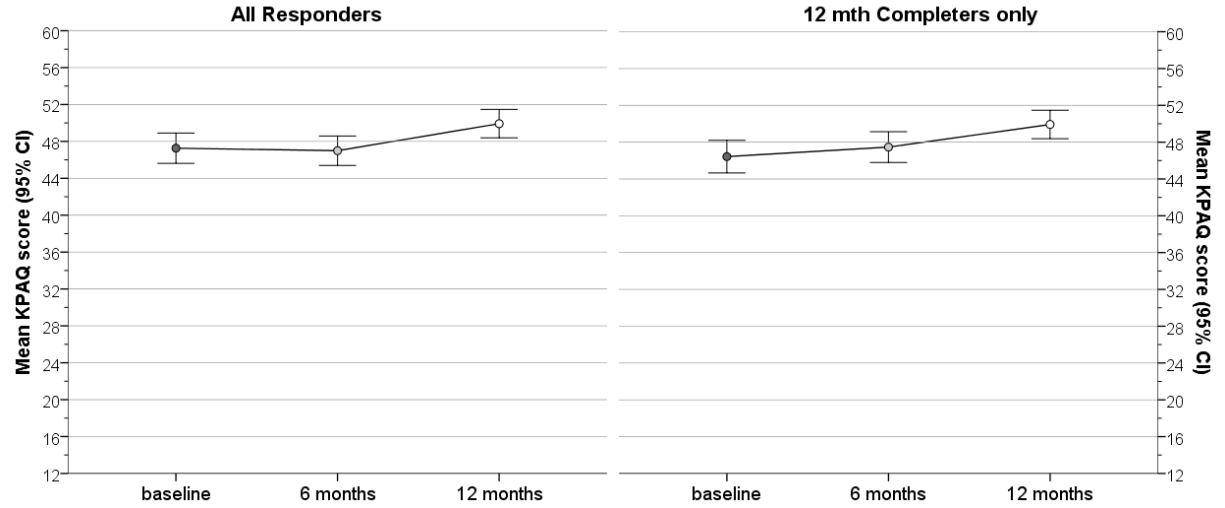


Figure 10.27 KPAQ - means (95% CI) all time points



10.3.3 Scoliosis Research Society questionnaire (SRS-22r)

Descriptive statistics are presented in Table 10.16 to Table 10.20 and illustrated in Figure 10.28 to Figure 10.47. A summary of statistical analyses is provided in Table 10.21.Table 1.1

10.3.3.1 Function scale

On average, participants scored highly on the function scale across all time-points (Table 10.16). Due to the highly-skewed nature of the data (Figure 10.28 and Figure 10.29), a 1-way Friedman's ANOVA was performed to assess differences between time-points. The results were not statistically significant (F_r=.161, df=2, p=.923) indicating no differences in function scores between the 3 time-points.

Table 10.16 SRS22r function scale - descriptive statistics

SRS22r function (1 worst - 5 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	4.61	0.45	0.06	4.50, 4.73	4.80	4.30, 5.00	3.40	5.00	1 (1.7)
	C (n=42)	4.65	0.45	0.07	4.51, 4.79	4.80	4.40, 5.00	3.40	5.00	0
6 months	All (n=44)	4.60	0.56	0.08	4.43, 4.77	4.80	4.40, 5.00	2.60	5.00	14 (24.1)
	C (n=40)	4.63	0.55	0.09	4.45, 4.80	4.80	4.40, 5.00	2.60	5.00	2 (4.8)
12 months	All/C (n=38)	4.68	0.54	0.09	4.51, 4.86	4.80	4.60, 5.00	2.60	5.00	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.3.3.2 Pain scale

Pain scores increased slightly (i.e. pain improved) from baseline to 12 months on average (Table 10.17). Statistical analysis resulted in a statistically significant main effect of time-point ($F(2, 68) =4.56$; $p=0.014$; $\eta^2=.118$) (Table 10.21

Table 10.21). Contrasts revealed that pain score at 12 months was greater than at baseline ($F(1, 34) = 9.413$; $p = .004$; $\eta^2 = .117$) indicating that pain improved over time.

There was no statistically significant between-subject effect of trial arm ($F(1, 34) = 3.25$; $p = 0.08$; $\eta^2 = .087$) or interaction between time-point and arm ($F(2, 68) = 2.76$; $p = 0.071$; $\eta^2 = .075$).

Table 10.17 SRS22r pain scale - descriptive statistics

SRS22r pain (1 worst - 5 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	3.96	0.76	0.10	3.76, 4.17	4.20	3.40, 4.60	1.80	5.00	1 (1.7)
	C (n=42)	4.00	0.74	0.11	3.77, 4.23	4.20	3.55, 4.60	2.00	5.00	0
6 months	All (n=44)	4.08	0.65	0.10	3.88, 4.28	4.10	3.64, 4.75	2.60	5.00	14 (24.1)
	C (n=40)	4.12	0.67	0.11	3.91, 4.33	4.20	3.80, 4.80	2.60	5.00	2 (4.8)
12 months	All/C (n=38)	4.20	0.76	0.12	3.95, 4.45	4.40	3.95, 4.80	1.40	5.00	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.3.3.3 Self-image scale

On average, self-image scores were generally lower (i.e. worse) than other SRS-22r subscales but were relatively consistent across time-points (

Table 10.18).

There was no statistically significant main effect of time-point (F(2, 70) =0.48; p=0.624; η^2=.013), nor was there a statistically significant interaction between time-point and trial arm conditions (F(2, 70) =0.62; p=0.542; η^2=.017) (

Table 10.21).

Table 10.18 SRS22r self-image scale - descriptive statistics

SRS22r self-image (1 worst - 5 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	3.41	0.73	0.10	3.22, 3.61	3.40	2.90, 3.80	1.80	5.00	1 (1.7)
	C (n=42)	3.41	0.76	0.12	3.18, 3.65	3.40	2.80, 3.85	1.80	5.00	0
6 months	All (n=44)	3.49	0.87	0.13	3.22, 3.75	3.60	2.65, 4.00	1.40	5.00	14 (24.1)
	C (n=40)	3.49	0.84	0.13	3.22, 3.76	3.60	2.70, 4.00	1.40	5.00	2 (4.8)
12 months	All/C (n=38)	3.52	0.90	0.15	3.23, 3.82	3.60	3.00, 4.00	1.00	5.00	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.3.3.4 Mental health scale

Mental health scores displayed very little difference on average between time-points (Table 10.19), and there were no statistically significant main effects of time-point ($F(2, 70) = 0.48$; $p=0.623$; $\eta^2=.013$) or interaction between time-point and trial arm conditions ($F(2, 70) = 2.39$; $p=0.099$; $\eta^2=.064$) (

Table 10.21).

Table 10.19 SRS22r mental health scale - descriptive statistics

SRS22r mental health (1 worst - 5 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	3.90	0.89	0.12	3.66, 4.14	4.20	3.30, 4.60	1.80	5.00	1 (1.7)
	C (n=42)	3.88	0.88	0.14	3.61, 4.15	4.10	3.15, 4.60	2.00	5.00	0
6 months	All (n=44)	3.90	0.95	0.14	3.62, 4.19	4.20	3.25, 4.60	1.60	5.00	14 (24.1)
	C (n=40)	3.91	0.94	0.15	3.61, 4.21	4.20	3.25, 4.60	1.60	5.00	2 (4.8)
12 months	All/C (n=38)	4.01	0.92	0.15	3.71, 4.31	4.20	3.20, 4.85	1.60	5.00	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.3.3.5 Subtotal

There was a slight improvement in SRS-22r subtotal scores over time (Table 10.20) but this did not result in a statistically significant main effect of time-point ($F(2, 70)=1.07$; $p=0.348$; $\eta^2=.003$) or interaction between time-point and trial arm conditions ($F(2, 70)=2.65$; $p=0.078$; $\eta^2=.007$) (

Table 10.21).

Table 10.20 SRS22r subtotal - descriptive statistics

SRS22r total score (1 worst - 5 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	3.97	0.58	0.08	3.81, 4.13	4.10	3.50, 4.43	2.70	4.85	1 (1.7)
	C (n=42)	3.99	0.60	0.09	3.80, 4.17	4.13	3.50, 4.45	2.70	4.85	0
6 months	All (n=44)	4.02	0.59	0.09	3.84, 4.20	4.13	3.45, 4.49	2.85	4.95	14 (24.1)
	C (n=40)	4.04	0.58	0.09	3.85, 4.22	4.18	3.45, 4.53	2.85	4.95	2 (4.8)
12 months	All/C (n=38)	4.10	0.65	0.11	3.89, 4.32	4.28	3.81, 4.51	2.20	4.90	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.21 Summary of statistical analyses - SRS-22r

analysis	n	interaction	type (ε)	F	df_M	df_R	p-value	effect size, η^2
SRS-22r								
pain	36	timepoint	SA (0.998)	4.56	2	68	0.014*	0.118
		timepoint x arm		2.76			0.071	0.075
self-image	37	timepoint	SA (0.843)	0.48	2	70	0.624	0.013
		timepoint x arm		0.62			0.542	0.017
mental health	37	timepoint	SA (0.991)	0.48	2	70	0.623	0.013
		timepoint x arm		2.39			0.099	0.064
Total score	37	timepoint	SA (0.925)	1.07	2	70	0.348	0.03
		timepoint x arm		2.65			0.078	0.07

* = statistically significant; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

Figure 10.28 SRS-22r function score - All Responders histograms all time points

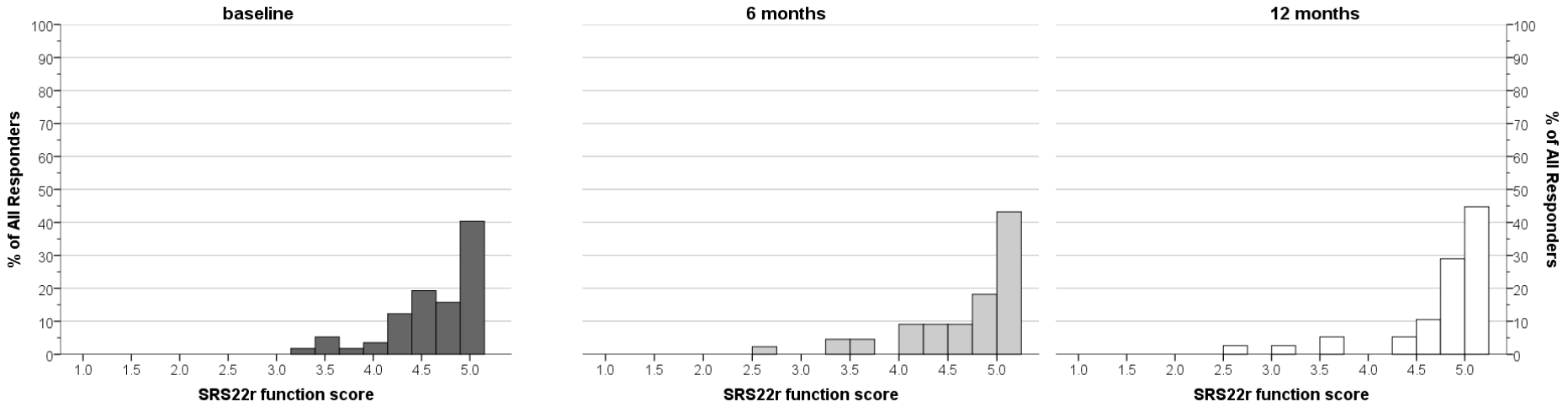


Figure 10.29 SRS-22r function score - 12 mth Completers only histograms

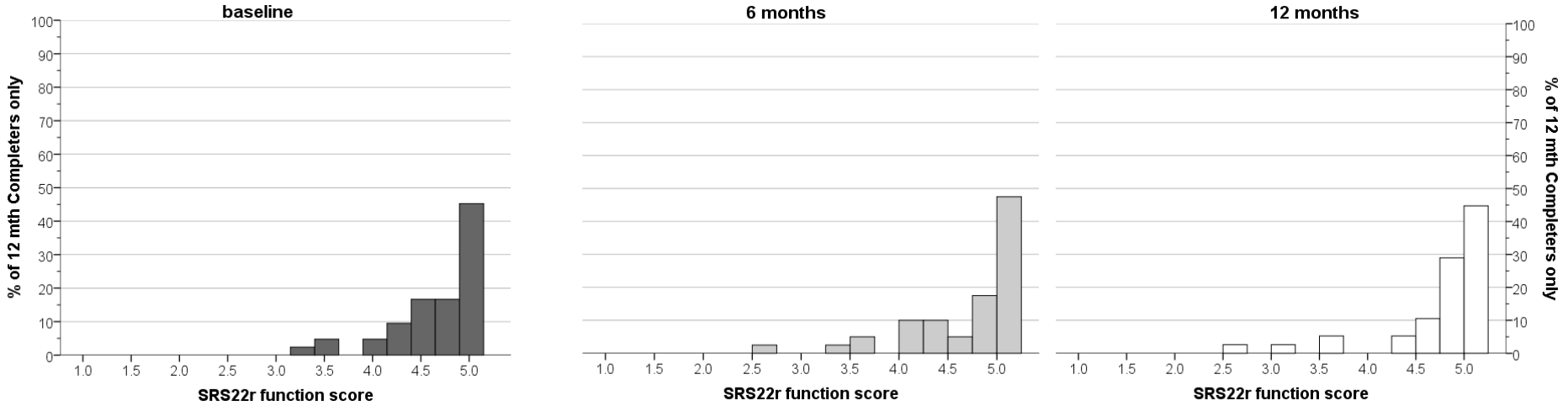


Figure 10.30 SRS22r function scale - boxplots

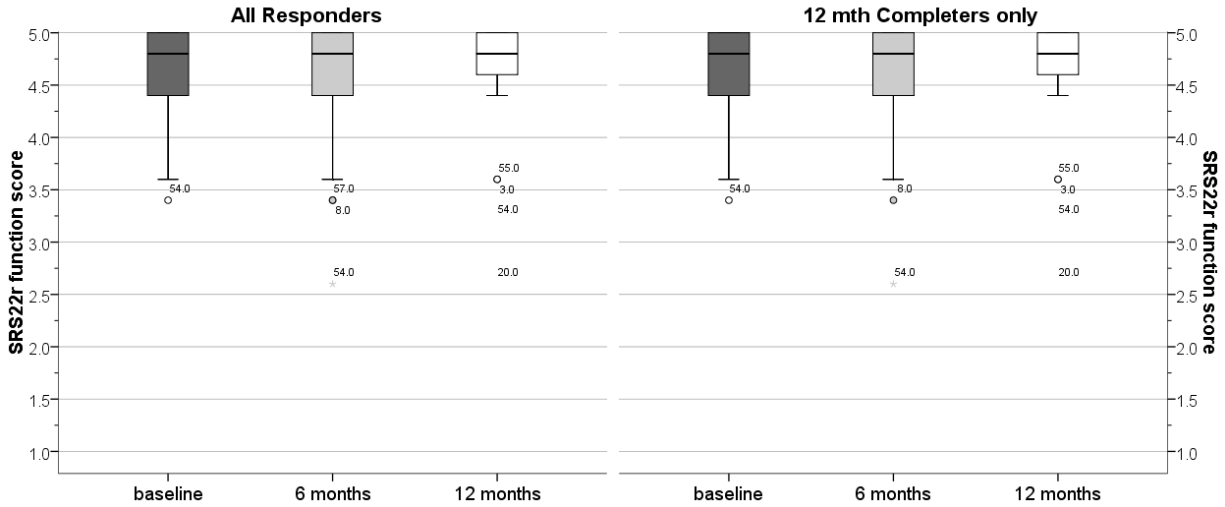


Figure 10.31 SRS22r function scale - means (95% CI)

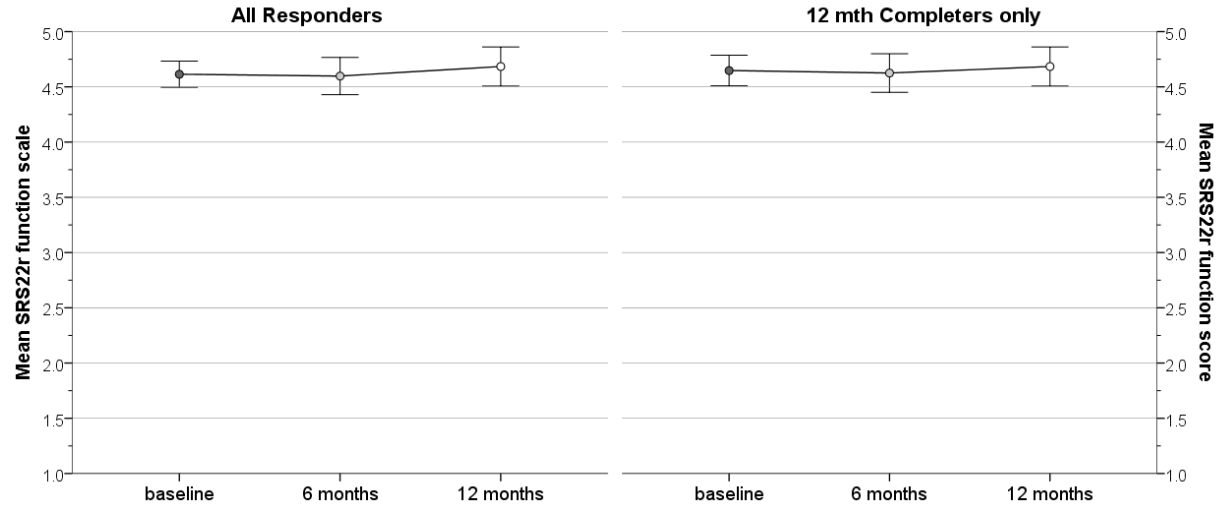


Figure 10.32 SRS22r pain score - All Responders histograms

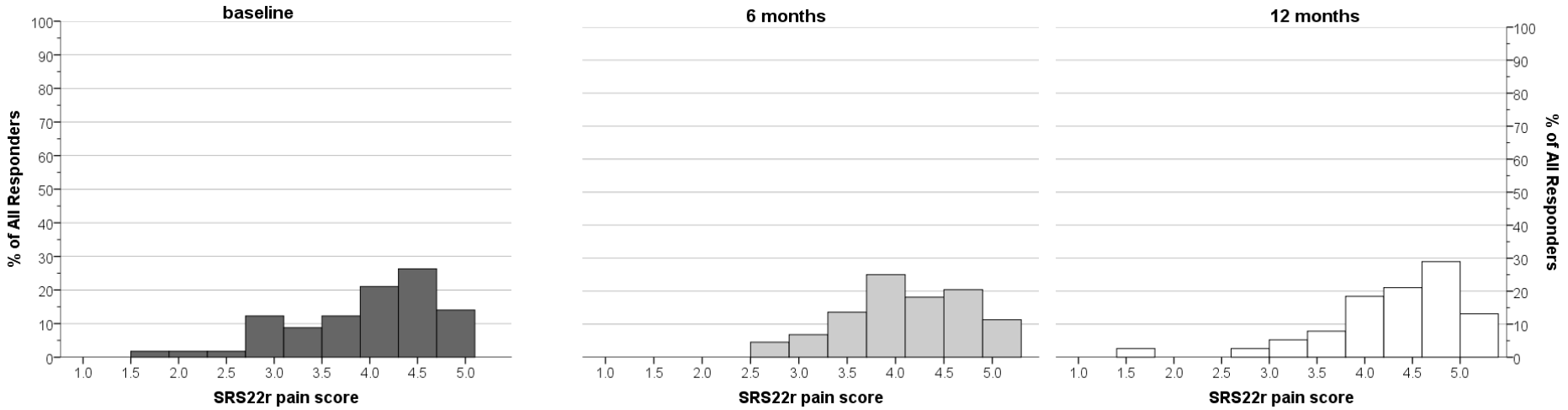


Figure 10.33 SRS22r pain score - 12 mth Completers only histograms

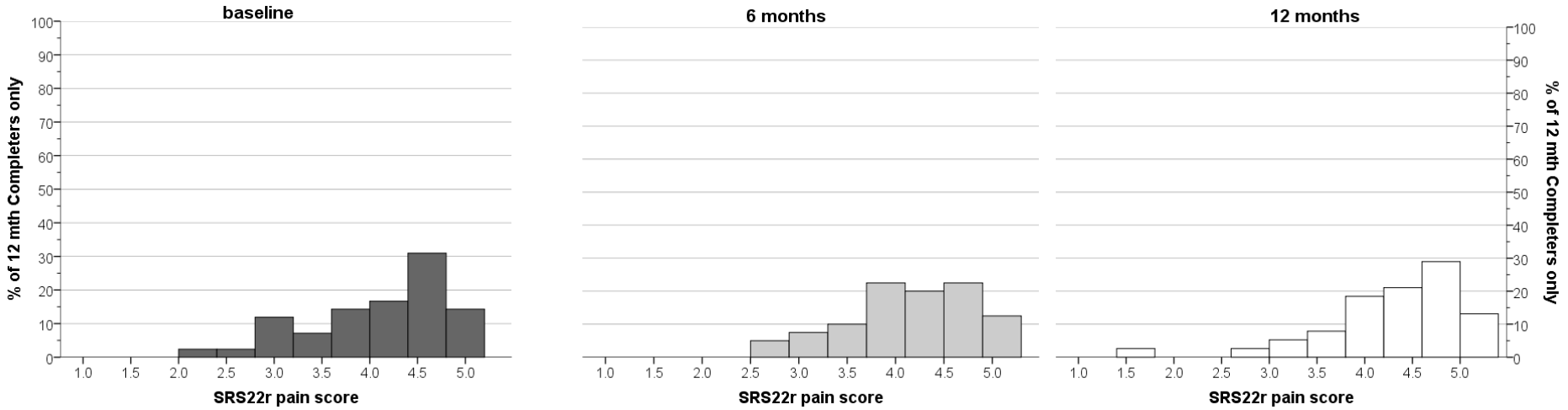


Figure 10.34 SRS22r pain scale - boxplots

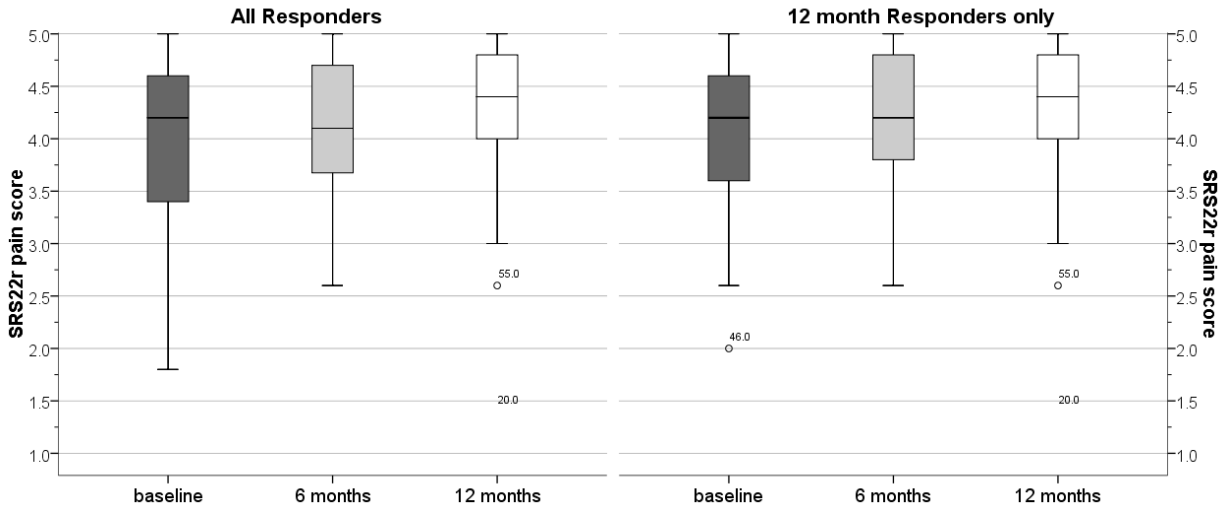


Figure 10.35 SRS22r pain scale - means (95% CI)

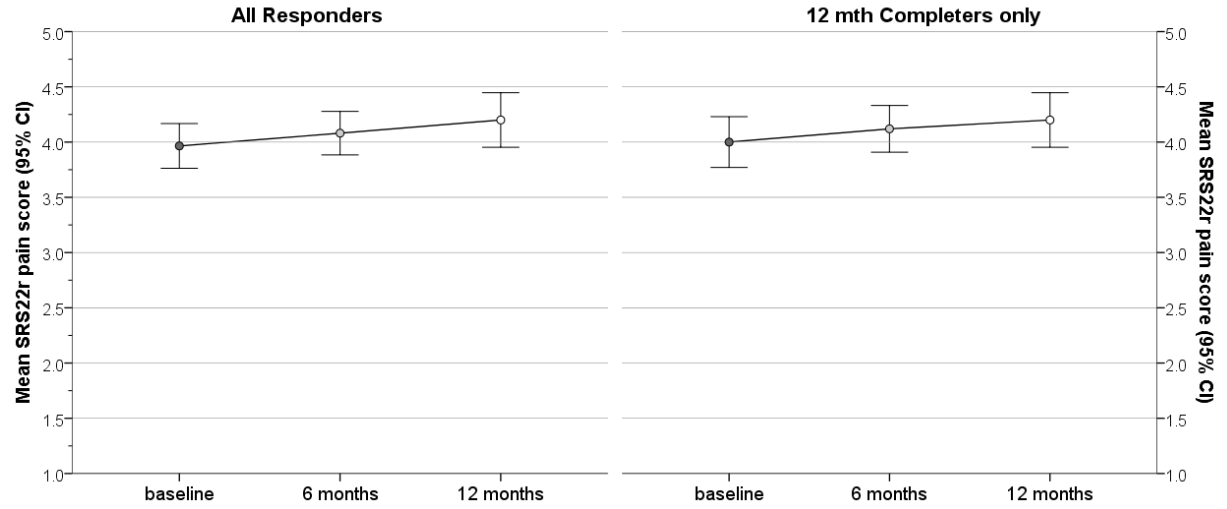


Figure 10.36 SRS22r self-image score - All Responders histograms

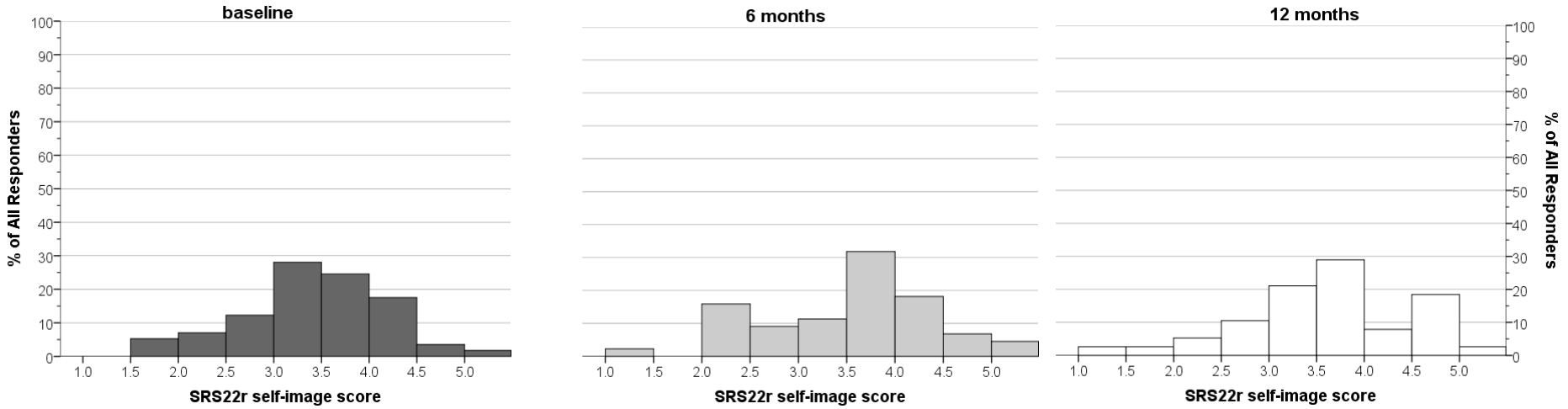


Figure 10.37 SRS22r self-image score - 12 mth Completers only histograms

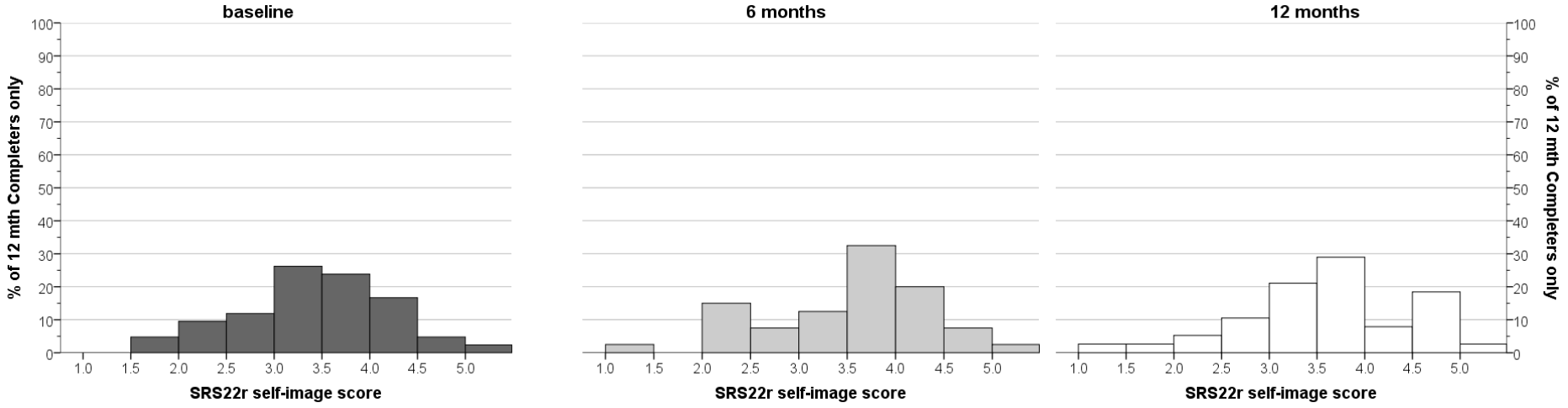


Figure 10.38 SRS22r self-image scale - boxplots

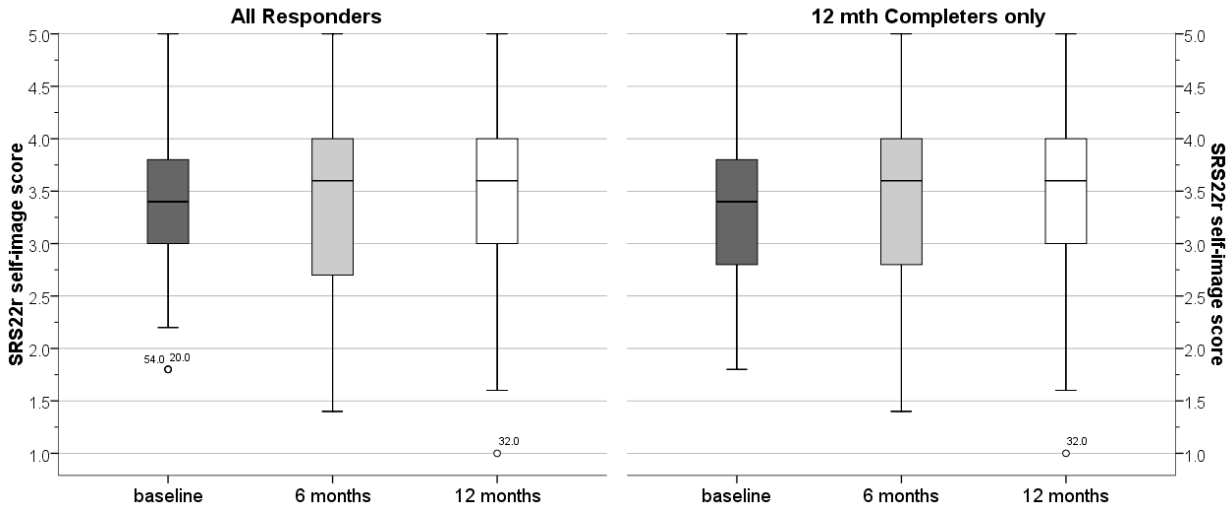


Figure 10.39 SRS22r self-image scale - means (95% CI)

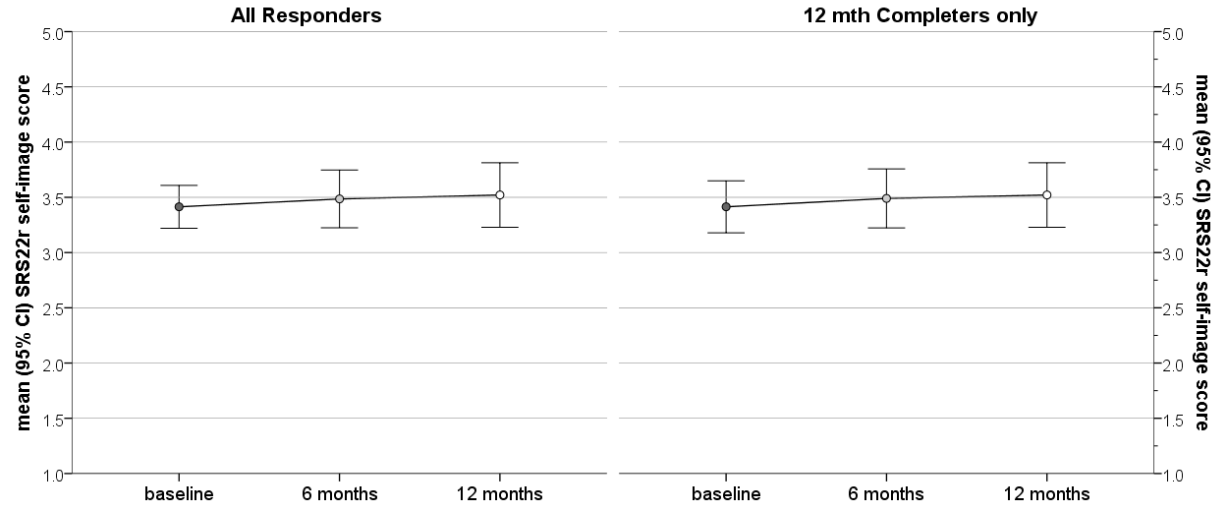


Figure 10.40 SRS22r mental health score - All Responders histograms

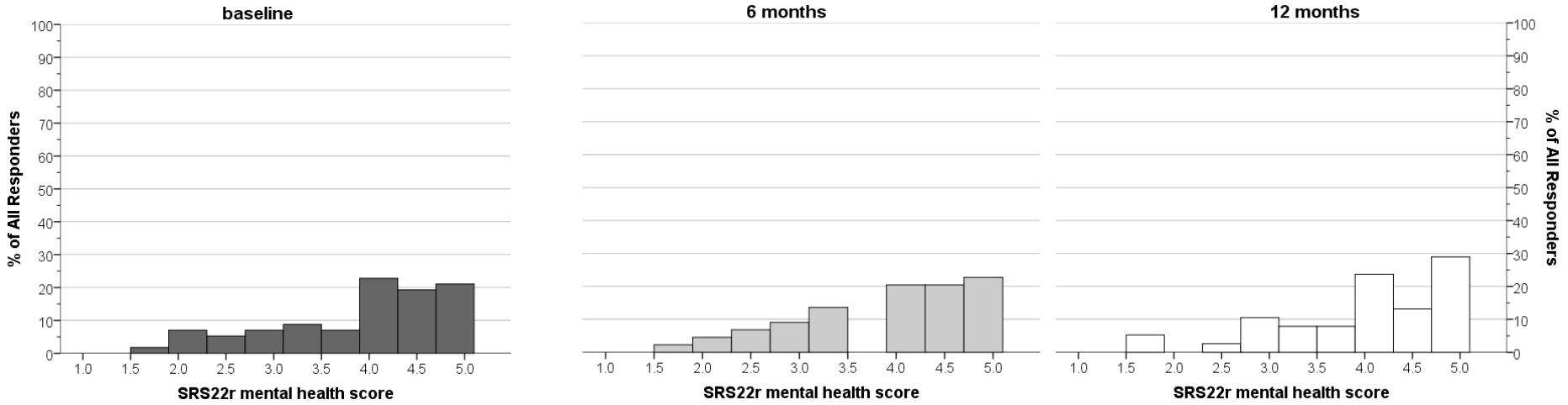


Figure 10.41 SRS22r mental health score - 12 mth Completers only histograms

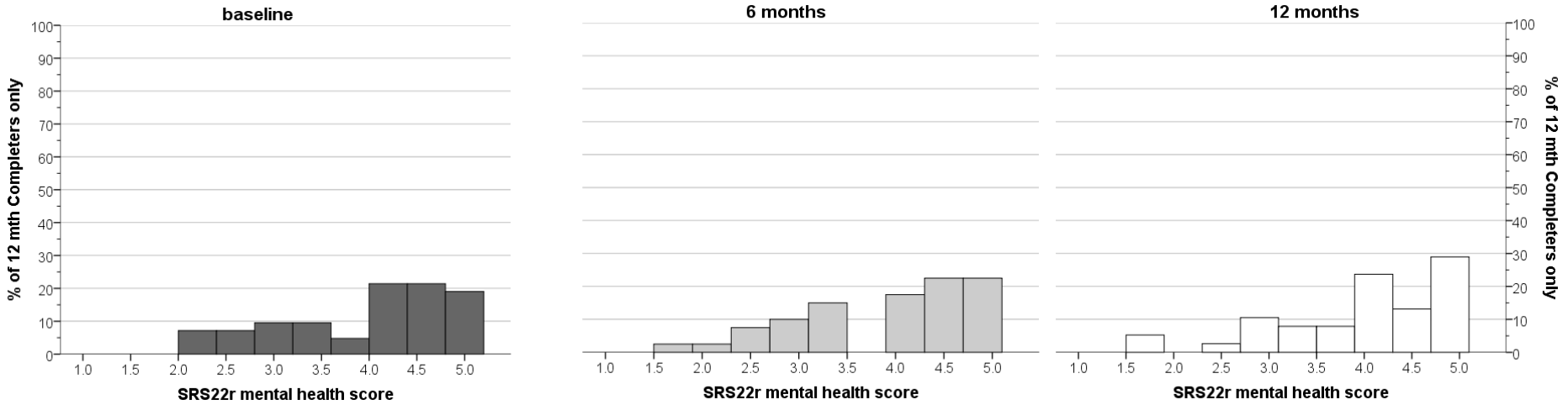


Figure 10.42 SRS22r mental health scale - boxplots

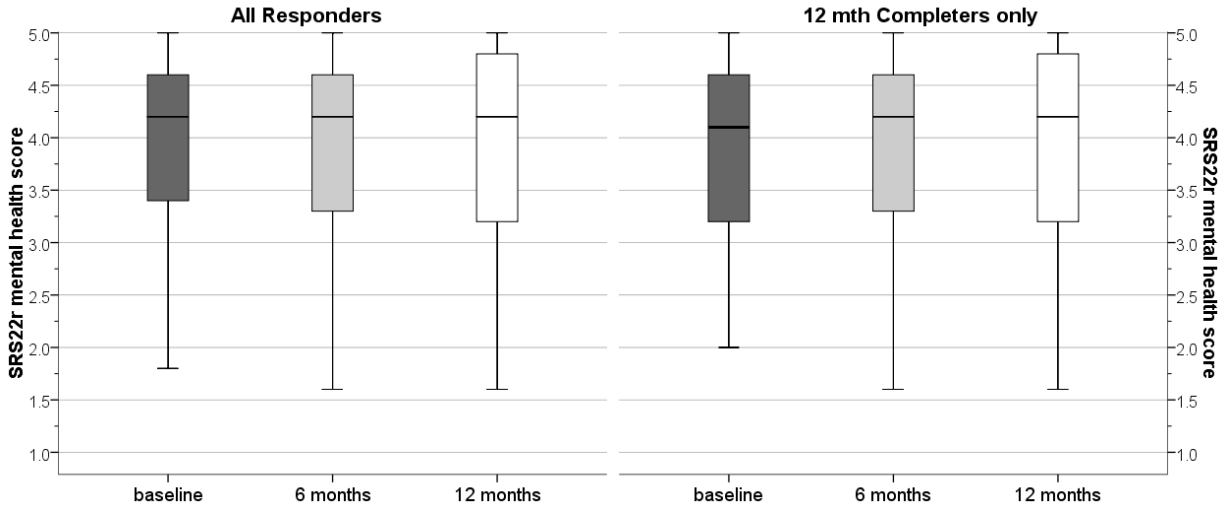


Figure 10.43 SRS22r mental health scale - means (95% CI)

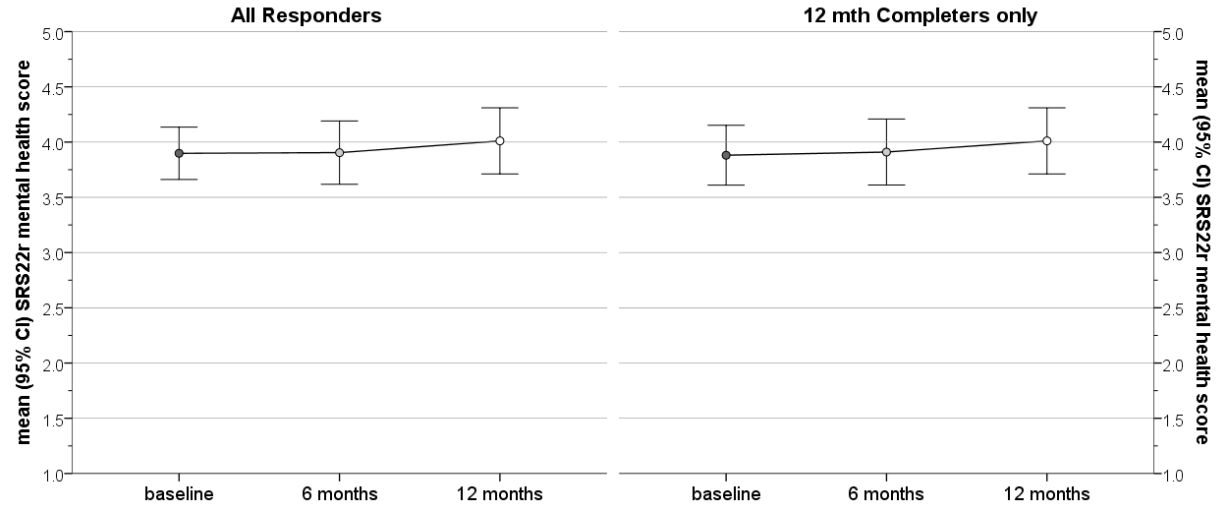


Figure 10.44 SRS22r total score - All Responders histograms

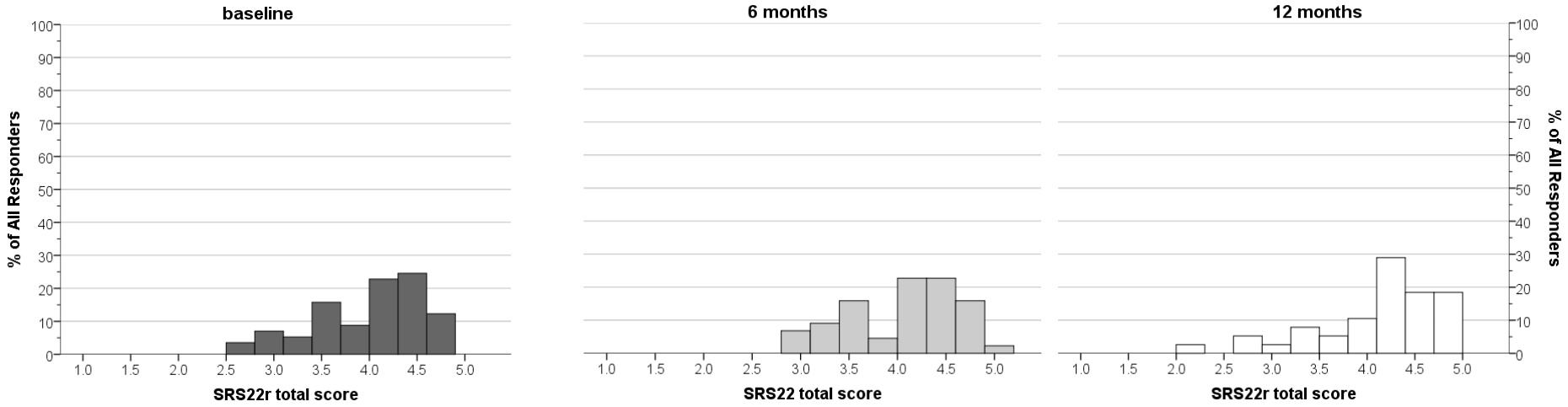


Figure 10.45 SRS22r total score - 12 mth Completers only

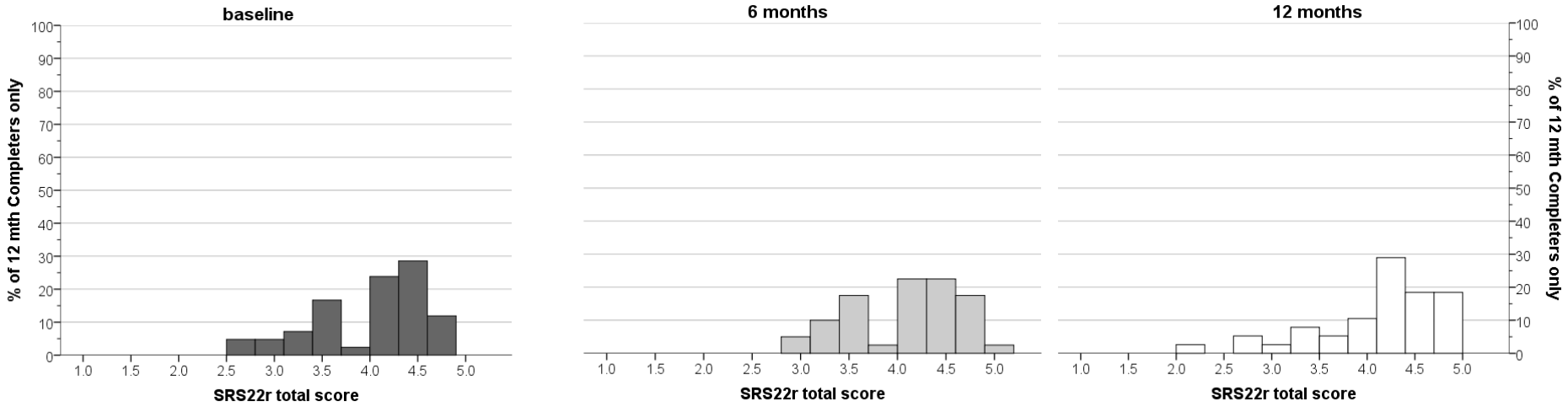


Figure 10.46 SRS22r total score - boxplots

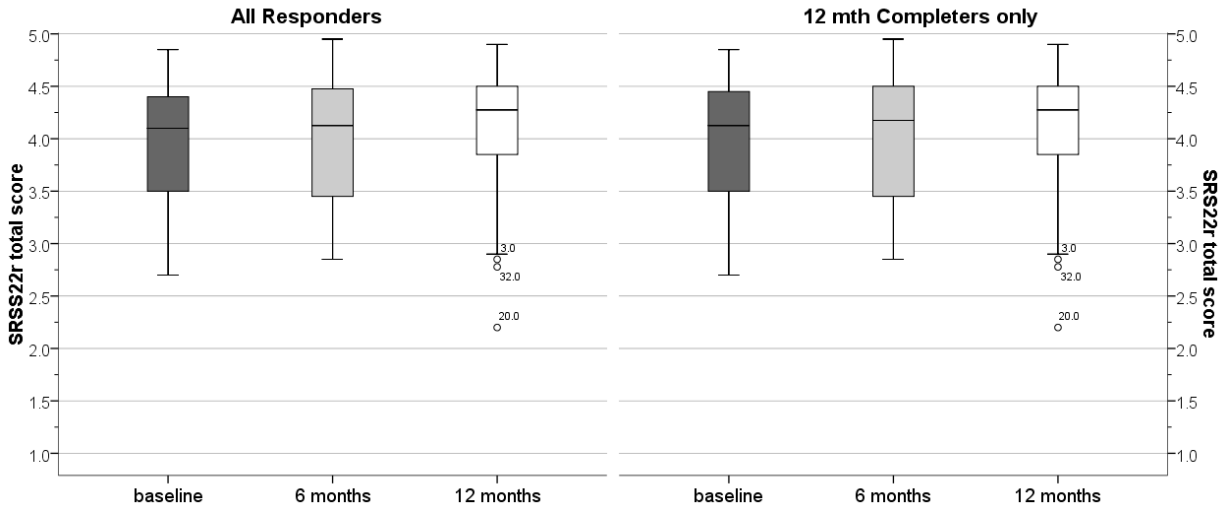
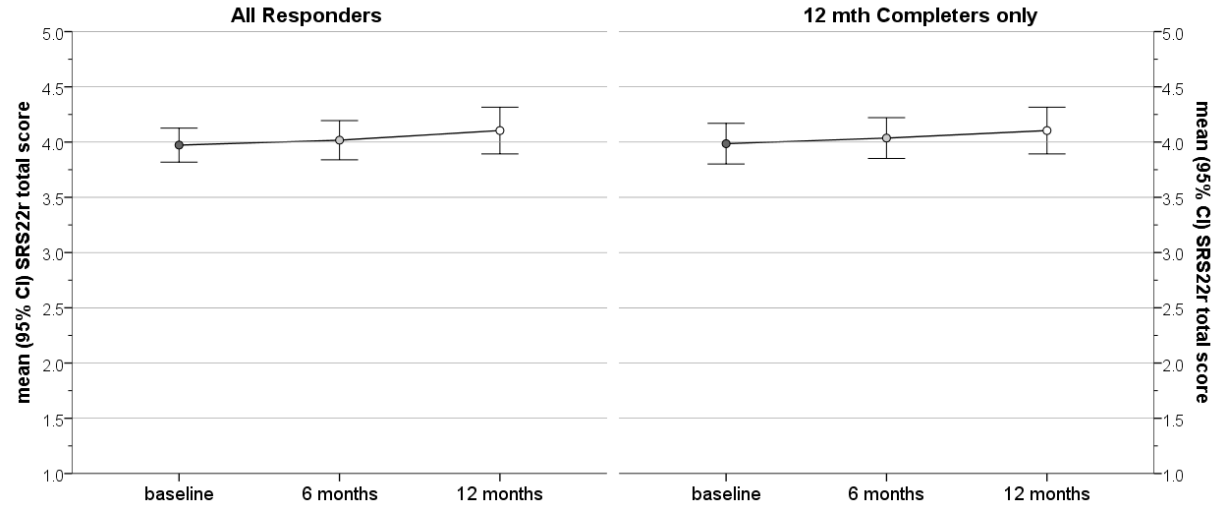


Figure 10.47 SRS22r total score - means (95% CI)



10.3.4 EQ5D - 3L

Descriptive statistics are presented in Table 10.22 and Table 10.23 and illustrated in Figure 10.48 to Figure 10.56. Results of statistical analysis for the 5 domains are described in Table 10.24.

10.3.4.1 EQ5D domains

Responses for each domain were combined into two categories: problems or no problems (Table 10.23). Statistical analysis was then conducted to determine differences in the proportions of these two categories between time-points. There were some differences between time-points for some domains, most notably, the reduction in the proportion of participants reporting pain at 12 months. However, the results of statistical analysis indicate that there was no difference in proportions over time for any of mobility, self-care, activity, pain or anxiety domains (Table 10.24).

10.3.4.2 Health state VAS

On average, participants EQ5D VAS scores improved slightly across all time-points (Table 10.22). Due to the highly-skewed nature of the data (Figure 10.53 and Figure 10.54), a 1-way Friedman's ANOVA was performed to assess differences between time-points. The results were not statistically significant (F_r1.389, df=2, p=.499) indicating no differences in perceived health state between the 3 time-points.

Table 10.22 EQ5D health state VAS - descriptive statistics

EQ5D health state (0 worst - 100 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	77.65	19.17	2.54	72.56, 82.73	85.00	68.0, 90.0	20	100	1 (1.7)
	C (n=42)	75.88	20.13	3.11	69.61, 82.15	81.50	69.0, 90.0	20	100	0
6 months	All (n=44)	78.23	17.10	2.58	73.03, 83.43	81.50	70.0, 90.0	30	100	14 (24.1)
	C (n=40)	77.58	16.57	2.62	72.27, 82.88	80.00	70.0, 90.0	30	100	2 (4.8)
12 months	All/C (n=38)	79.37	22.02	3.57	72.13, 86.61	85.00	75.25, 95.00	15	100	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.23 EQ5D - 3L frequencies

time point	status*	1 no problems	2 some problems	3 extreme problems	2 + 3 combined problems	missing
EQ5D mobility						
baseline	All (n=57)	47 (82.5)	9 (15.8)	1 (1.8)	10 (17.5)	1 (1.7)
	C (n=42)	35 (83.3)	6 (14.3)	1 (2.4)	7 (16.7)	0
6 months	All (n=44)	39 (88.6)	5 (11.4)	0	5 (11.4)	14 (24.1)
	C (n=40)	35 (87.5)	5 (12.5)	0	5 (12.5)	2 (4.8)
12 months	All/C (n=38)	36 (94.7)	2 (5.3)	0	2 (5.3)	20 (34.5) / 4 (9.5)
EQ5D self-care						
baseline	All (n=57)	56 (98.2)	1 (1.8)	0	1 (1.8)	1 (1.7)
	C (n=42)	41 (97.6)	1 (2.4)	0	1 (2.4)	0
6 months	All (n=44)	43 (97.7)	1 (2.3)	0	1 (2.3)	14 (24.1)
	C (n=40)	39 (97.5)	1 (2.5)	0	1 (2.5)	2 (4.8)
12 months	All/C (n=38)	36 (94.7)	2 (5.3)	0	2 (5.3)	20 (34.5) / 4 (9.5)
EQ5D activity						
baseline	All (n=57)	45 (78.9)	12 (21.1)	0	12 (12.1)	1 (1.7)
	C (n=42)	33 (78.6)	9 (21.4)	0	9 (21.4)	0
6 months	All (n=44)	35 (79.5)	9 (20.5)	0	9 (20.5)	14 (24.1)
	C (n=40)	33 (82.5)	7 (17.5)	0	7 (17.5)	2 (4.8)
12 months	All/C (n=38)	34 (89.5)	4 (10.5)	0	4 (10.4)	20 (34.5) / 4 (9.5)
EQ5D pain						
baseline	All (n=57)	19 (33.3)	37 (64.9)	1 (1.8)	38 (66.7)	1 (1.7)
	C (n=42)	16 (38.1)	25 (59.5)	1 (2.4)	26 (61.9)	0
6 months	All (n=44)	18 (40.9)	25 (56.8)	1 (2.3)	26 (59.1)	14 (24.1)
	C (n=40)	17 (42.5)	22 (55.0)	1 (2.5)	23 (57.5)	2 (4.8)
12 months	All/C (n=38)	21 (55.3)	15 (39.5)	2 (5.3)	17 (44.7)	20 (34.5) / 4 (9.5)
EQ5D anxiety						
baseline	All (n=57)	42 (73.7)	12 (21.1)	3 (5.3)	15 (26.3)	1 (1.7)
	C (n=42)	31 (73.8)	8 (19.0)	3 (7.1)	11 (26.2)	0
6 months	All (n=44)	31 (70.5)	12 (27.3)	1 (2.3)	13 (29.5)	14 (24.1)
	C (n=40)	28 (70.0)	11 (27.5)	1 (2.5)	12 (30.0)	2 (4.8)
12 months	All/C (n=38)	29 (76.3)	7 (18.4)	2 (5.3)	9 (23.7)	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.24 Summary of statistical analyses - EQ5D domains

scale	n	test statistic*	df	exact p-value
mobility	37	4.00	2	0.177
self-care	37	2.00	2	1.00
activity	37	1.56	2	0.590
pain	37	4.13	2	0.140
anxiety	37	1.00	2	0.739

*Cochran's Q

Figure 10.48 EQ5D Mobility

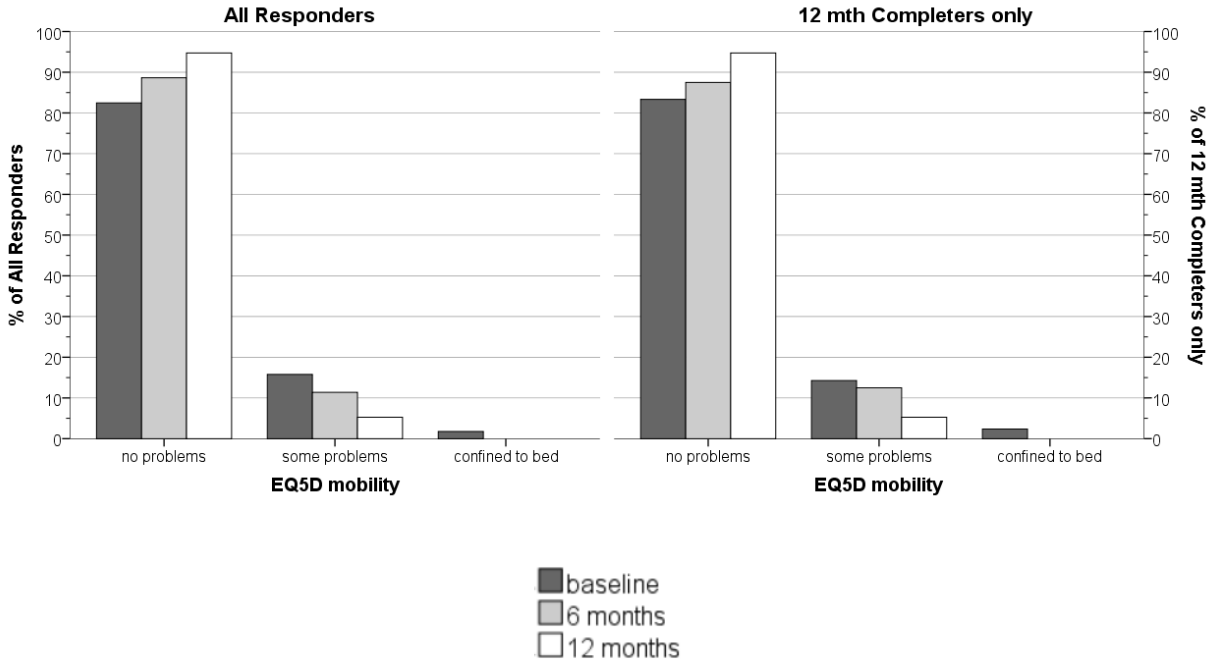


Figure 10.49 EQ5D Self-care

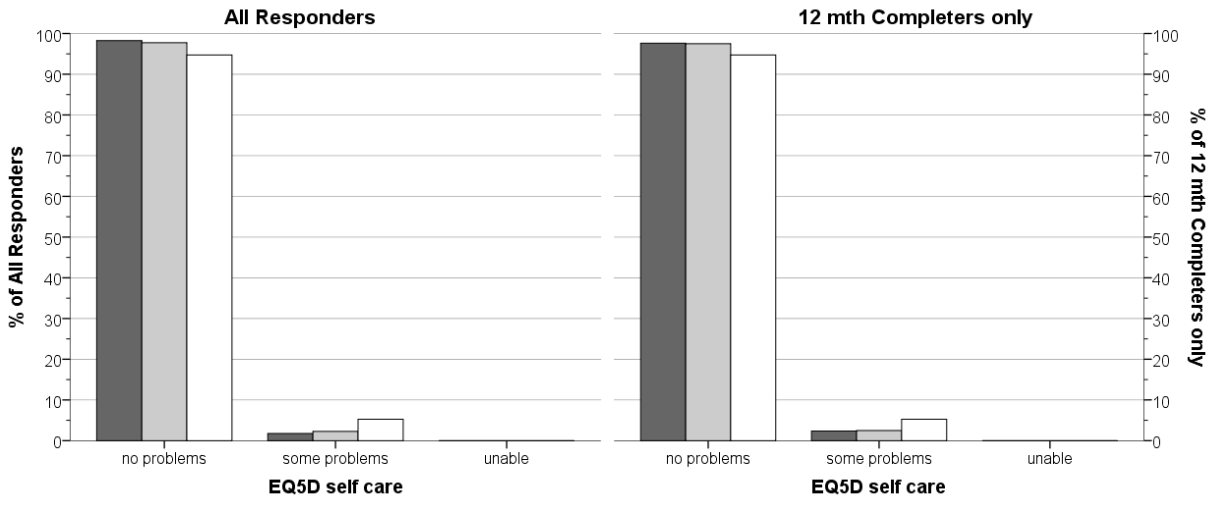


Figure 10.50 EQ5D Usual activities

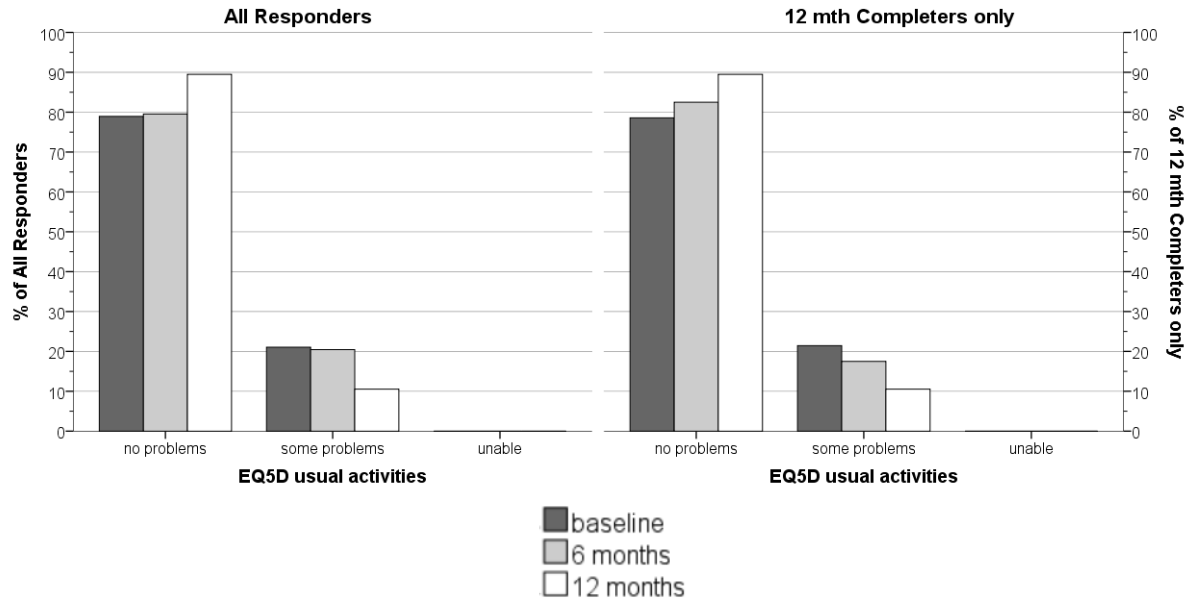


Figure 10.51 EQ5D Pain

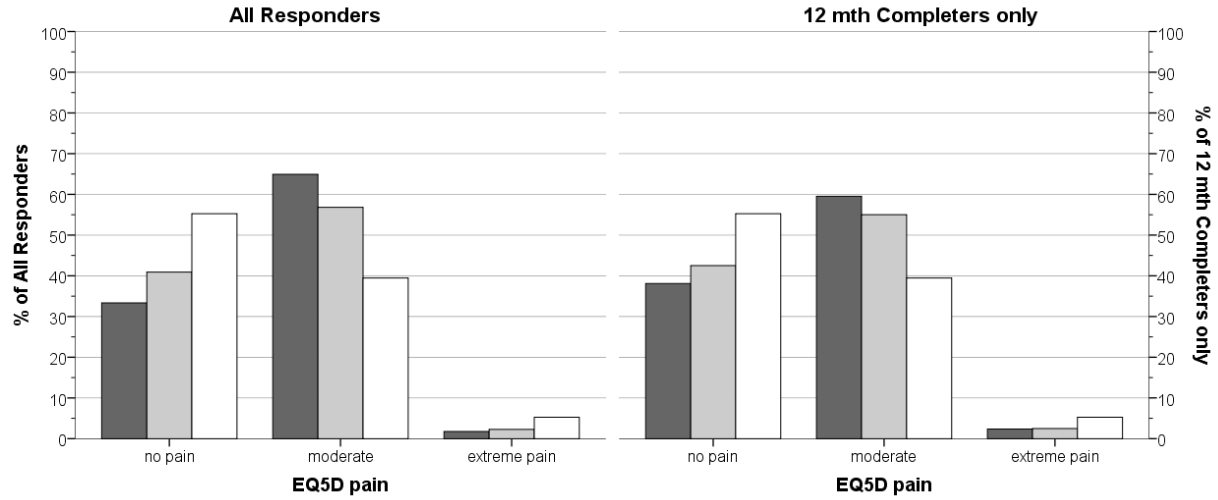


Figure 10.52 EQ5D Anxiety / depression

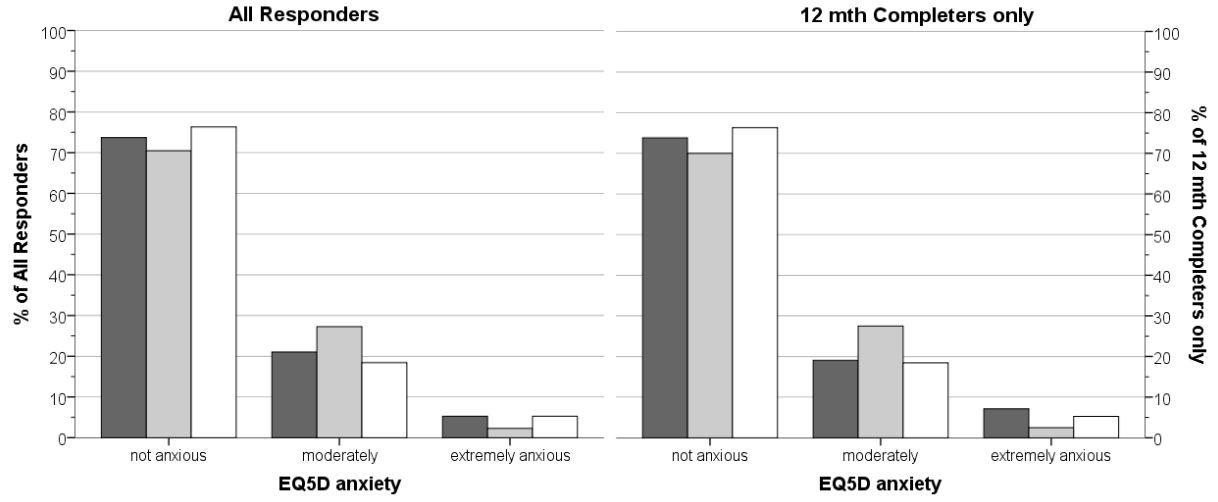


Figure 10.53 EQ5D health state - All Responders histograms

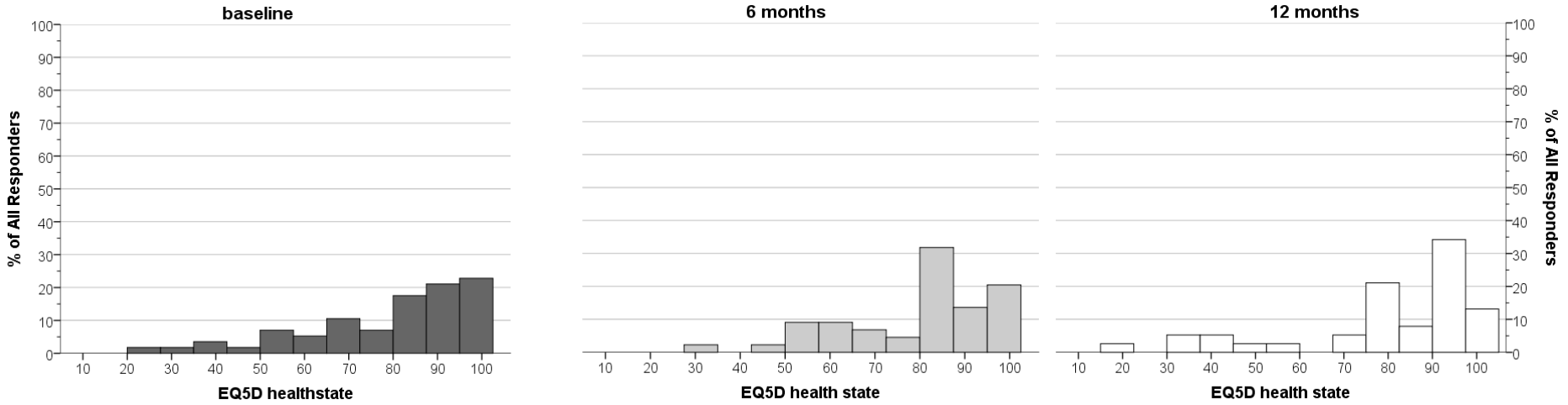


Figure 10.54 EQ5D health state - 12 mth Completers only histograms

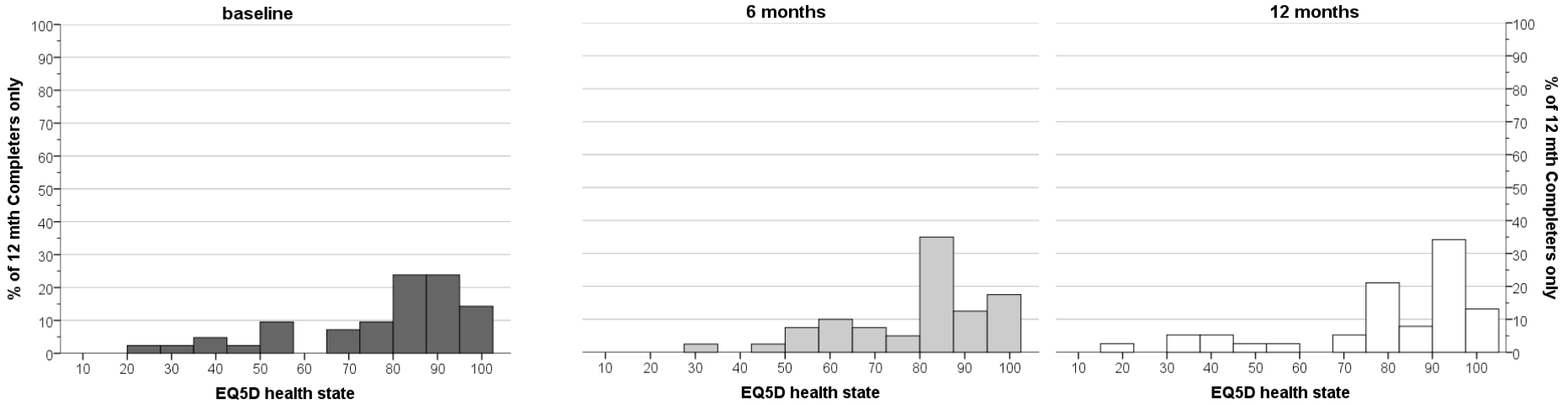


Figure 10.55 EQ5D health state - boxplots

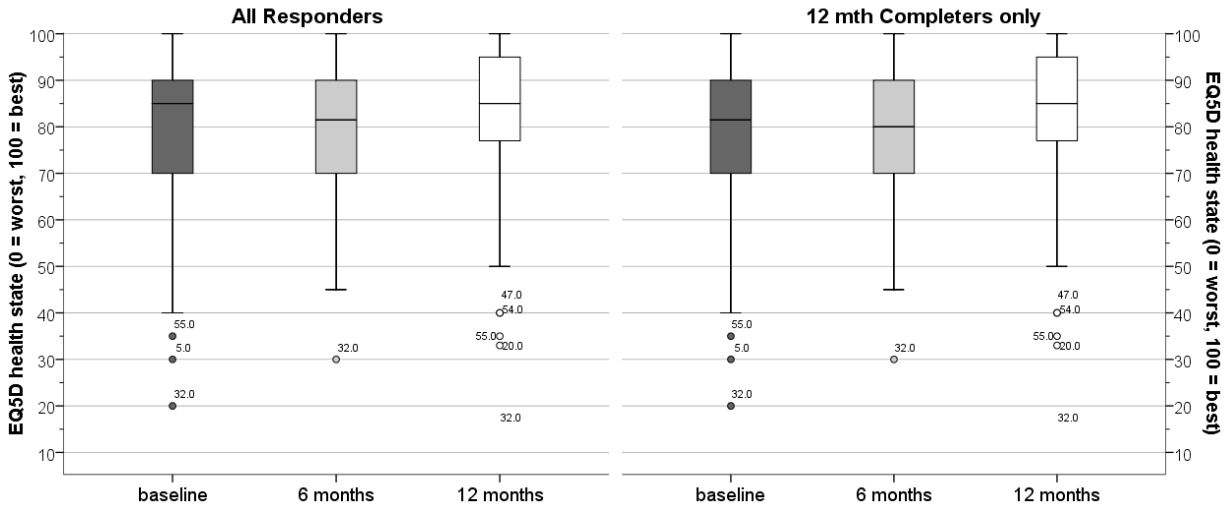
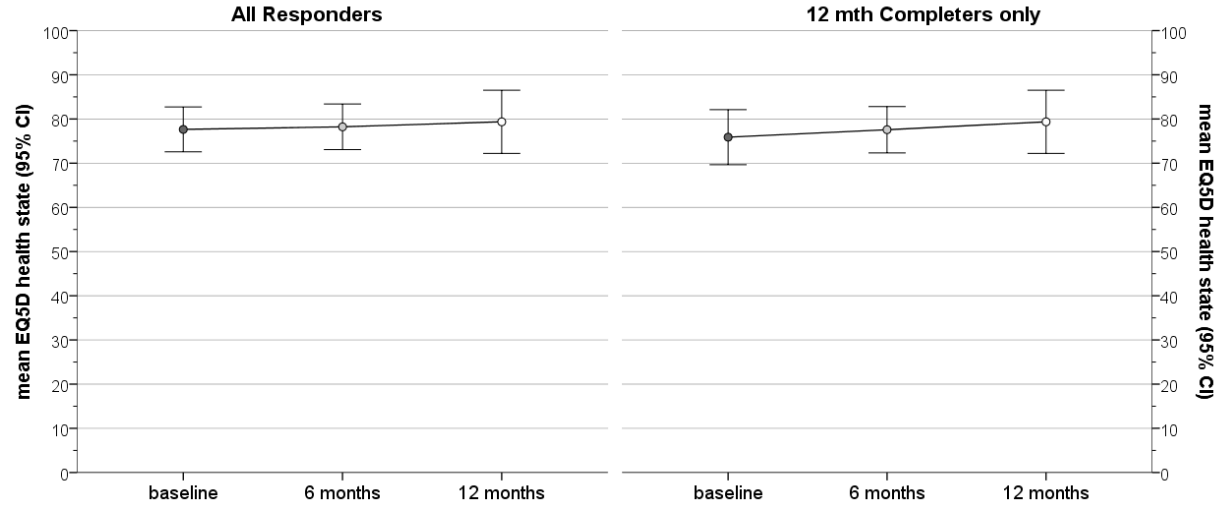


Figure 10.56 EQ5D health state - means (95% CI)



10.3.5 Paediatric Outcomes Data Collection Instrument (PODCI)

Descriptive statistics for all scales are presented in Table 10.25 to Table 10.27 and illustrated in Figure 10.57 to Figure 10.80. Summaries of statistical analyses are described in Table 10.28 and Table 10.29.

10.3.5.1 Upper extremity and physical function

In general, participants scored highly on this PODCI scale with small differences between time-points (Table 10.25). Due to the extremely-skewed nature of the data (Figure 10.57 and Figure 10.58), a 1-way Friedman's ANOVA was performed to assess differences between time-points. The results were statistically significant (F_r=.8.08, df=2, p=.018) indicating a difference between time-points. Step-down follow-up analysis revealed that there was a significant increase in 12 month follow-up scores compared to baseline (effect size, $r_{baseline\text{-}12mths}$=.267) and 6 month scores ($r_{6mths\text{-}12mths}$=.214). There was no significant difference between baseline and 6 month follow-up scores (p=.511, $r_{baseline\text{-}6mths}$=.120) (

Table 10.28).

Table 10.25 PODCI Upper extremity & physical function scores - descriptive statistics

PODCI Upper extremity & physical function (0 worst - 100 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	95.25	8.4	1.11	93.02, 97.47	100.00	93.75, 100	50	100	1 (1.7)
	C (n=42)	94.94	9.54	1.47	91.97, 97.91	100.00	91.67, 100	50	100	0
6 months	All (n=44)	95.45	7.82	1.18	93.08, 97.83	100.00	92.71, 100	63	100	14 (24.1)
	C (n=40)	95.21	8.09	1.28	92.62, 97.80	100.00	92.71, 100	63	100	2 (4.8)
12 months	All/C (n=38)	97.48	6.75	1.09	95.26, 99.70	100.00	100, 100	71	100	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.3.5.2 Transfers and basic mobility, Sports and physical functioning, Global function

Scoring for these three scales mirrored the high scores for the Upper extremity scale (Table 10.26). However, testing with 1-way Friedman ANOVA revealed no statistically significant differences between time-points for any of these scales (Transfers: F_r=.241, df=2, p=.886; Sports: F_r=.723, df=2, p=.697; Global: F_r=.298, df=2, p=.862) (Table 10.28).

Table 10.26 PODCI scale scores - descriptive statistics

PODCI Transfer & basic mobility (0 worst - 100 best)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	97.77	3.93	0.52	96.72, 98.81	100.00	96.97, 100	80	100	1 (1.7)
	C (n=42)	97.80	4.27	0.66	96.47, 99.13	100.00	96.97, 100	80	100	0
6 months	All (n=44)	97.77	3.93	0.52	96.72, 98.81	100.00	96.97, 100	80	100	1 (1.7)
	C (n=40)	97.59	4.63	0.73	96.11, 99.08	100.00	96.97, 100	79	100	2 (4.8)

12 months	All/C (n=38)	97.37	6.56	1.06	95.21, 99.52	100.00	99.24, 100	71	100	20 (34.5) / 4 (9.5)
PODCI Sports & physical functioning (0 worst - 100 best)										
baseline	All (n=57)	88.88	12.8	1.70	85.48, 92.28	91.67	84.03, 100	45.14	100	1 (1.7)
	C (n=42)	90.02	11.62	1.79	86.40, 93.64	91.67	86.11, 100	56.06	100	0
6 months	All (n=44)	90.01	12.14	1.83	86.32, 93.70	94.44	88.89, 99.31	50.00	100	14 (24.1)
	C (n=40)	90.63	11.95	1.89	86.81, 94.46	95.64	89.02, 100	50.00	100	2 (4.8)
12 months	All/C (n=38)	90.40	15.19	2.46	85.40, 95.39	95.83	87.5, 100	20.14	100	20 (34.5) / 4 (9.5)
PODCI Global (0 worst - 100 best)										
baseline	All (n=57)	89.83	9.04	1.20	87.43, 92.22	91.39	82.95, 97.56	58.39	100	1 (1.7)
	C (n=42)	90.02	9.59	1.48	87.03, 93.01	91.81	83.36, 97.80	58.39	100	0
6 months	All (n=44)	90.53	9.52	1.43	87.64, 93.42	93.54	87.72, 98.15	62.06	100	14 (24.1)
	C (n=40)	90.84	9.59	1.52	87.77, 93.91	94.03	87.83, 98.32	62.06	100	2 (4.8)
12 months	All/C (n=38)	90.78	11.50	1.87	87.00, 94.56	95.58	87.58, 98.33	53.95	100	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

10.3.5.3 Pain/comfort and Happiness

Scoring for these two scales was lower on average than previous scales (Table 10.27). The data was transformed (x^2) to correct for skew and lack of normality prior to evaluation using a mixed model repeat measures ANOVA as described previously. No statistically significant main effect of time-point was revealed (Pain: $F(2, 70)=0.29$, $p=0.746$, $\eta^2=.008$; Happiness: ($F(2, 70)=.67$, $p=0.515$, $\eta^2=.019$), nor was there a statistically significant interaction between time-point and arm for either of these scales (Pain: $F(2, 70)=1.27$, $p=0.287$, $\eta^2=.035$; Happiness: ($F(2, 70)=1.43$, $p=0.246$, $\eta^2=.039$) (Table 10.29).

Table 10.27 PODCI Pain/comfort & Happiness scores - descriptive statistics

time point	status*	mean	sd	SE	95% CI	median	IQR	min	max	missing n (%)
PODCI Pain/comfort (0 worst - 100 best)										
baseline	All (n=57)	77.41	19.13	2.53	72.33, 82.48	78.33	65, 93.33	32.78	100	1 (1.7)
	C (n=42)	77.31	20.80	3.21	70.83, 83.80	83.61	60.56, 93.33	32.78	100	0
6 months	All (n=44)	79.27	20.87	3.15	72.92, 85.61	85.83	63.19, 100	23.33	100	14 (24.1)
	C (n=40)	79.93	21.19	3.35	73.15, 86.71	86.67	65.14, 100	23.33	100	2 (4.8)
12 months	All/C (n=38)	77.88	24.18	3.92	69.93, 85.83	86.67	65.56, 95	21.67	100	20 (34.5) / 4 (9.5)
PODCI Happiness (0 worst - 100 best)										
baseline	All (n=57)	73.07	25.58	3.39	66.28, 79.86	80.00	55.00, 95.00	0	100	1 (1.7)
	C (n=42)	72.02	27.56	4.25	63.43, 80.61	77.50	53.75, 96.25	0	100	0
6 months	All (n=44)	71.68	28.45	4.29	63.03, 80.33	85.00	48.75, 95.00	5.00	100	14 (24.1)
	C (n=40)	72.22	27.44	4.34	63.44, 80.99	85.00	48.75, 95.00	5.00	100	2 (4.8)
12 months	All/C (n=38)	76.84	22.76	3.69	69.36, 84.32	82.50	65.00, 95.00	0	100	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.28 Summary of statistical analyses 1 - PODCI scales

analysis	n	test statistic, F_r	df	p-value
UE & Physical Function	37	8.083	2	0.018*
Transfers & basic mobility	37	0.241	2	0.886
Sports & physical functioning	37	0.723	2	0.697
Global function	37	0.298	2	0.862

* statistically significant; F_r = Friedman's ANOVA

Table 10.29 Summary of statistical analyses 2 - PODCI pain and happiness scales

analysis	n	interaction	type (ε)	F	df_M	df_R	p-value	effect size, η^2
Pain Comfort	37	timepoint	SA (0.991)	0.29	2	70	0.746	0.008
		timepoint x arm		1.27			0.287	0.035
Happiness	37	timepoint	SA (0.878)	0.67	2	70	0.515	0.019
		timepoint x arm		1.43			0.246	0.039

SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

Figure 10.57 PODCI upper extremity & physical function - All Responders histograms

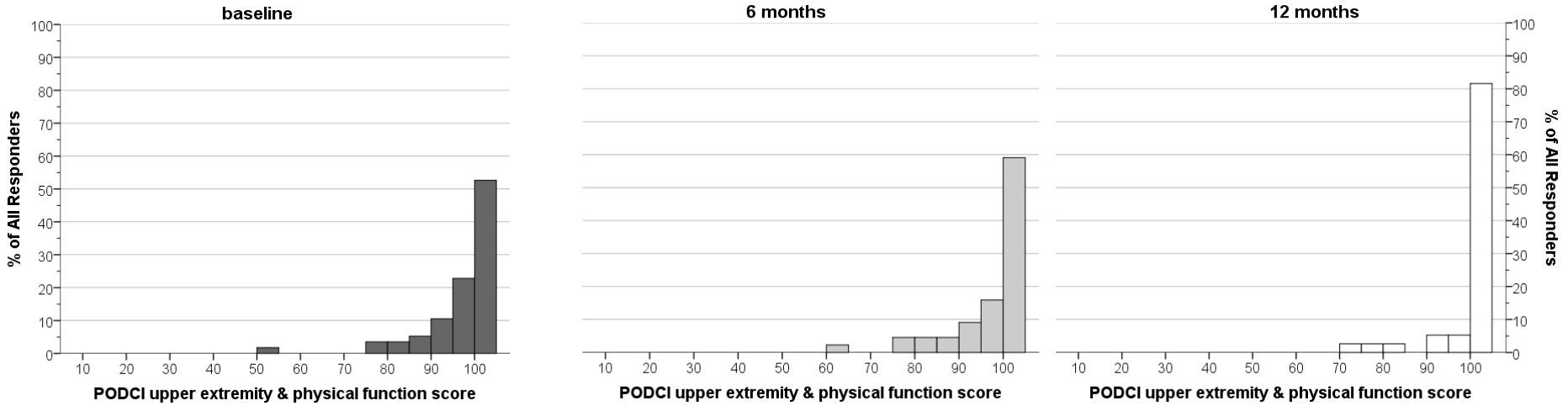


Figure 10.58 PODCI upper extremity & physical function - 12 mth Completers only histograms

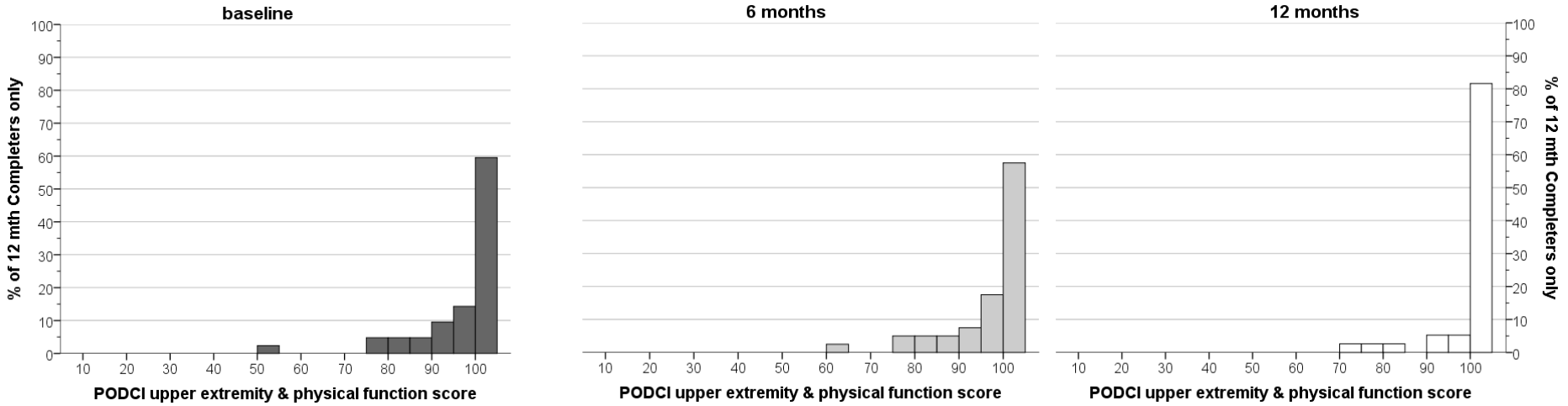


Figure 10.59 PODCI upper extremity & physical function - boxplots

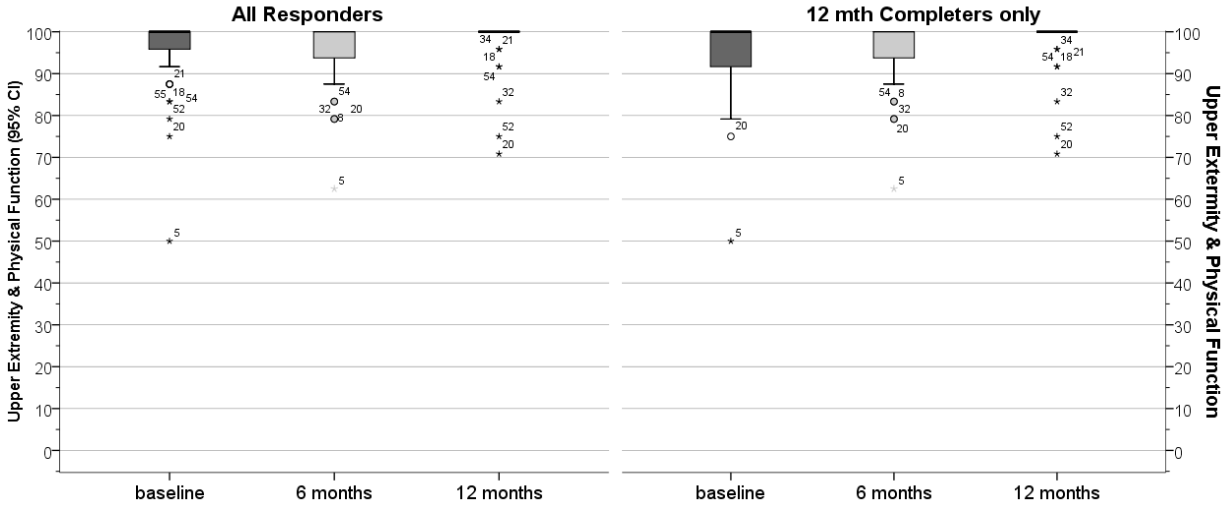


Figure 10.60 PODCI upper extremity & physical function - means (95% CI)

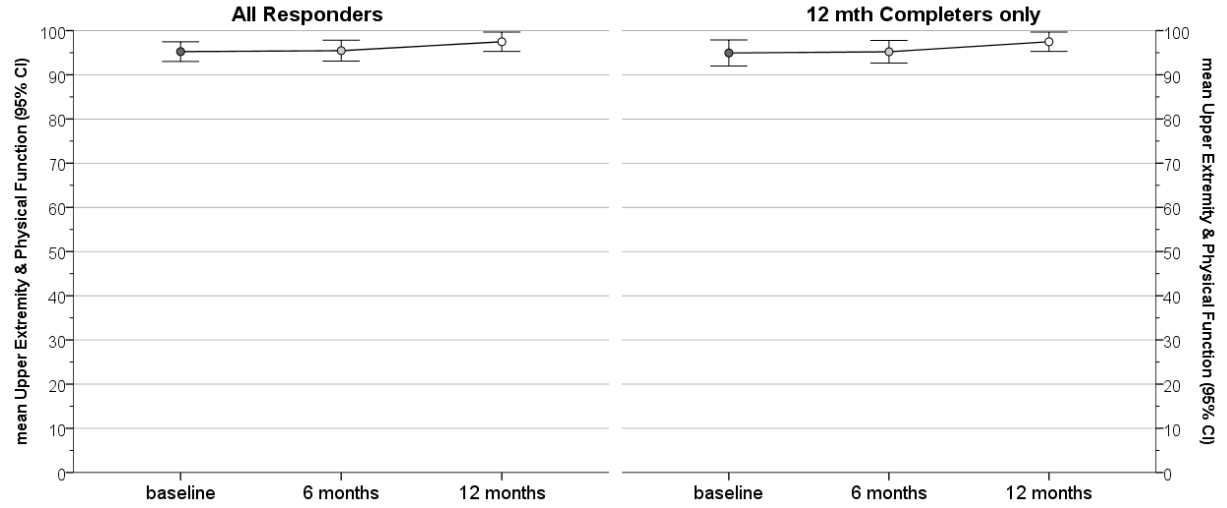


Figure 10.61 PODCI transfers & basic mobility - All Responders histograms

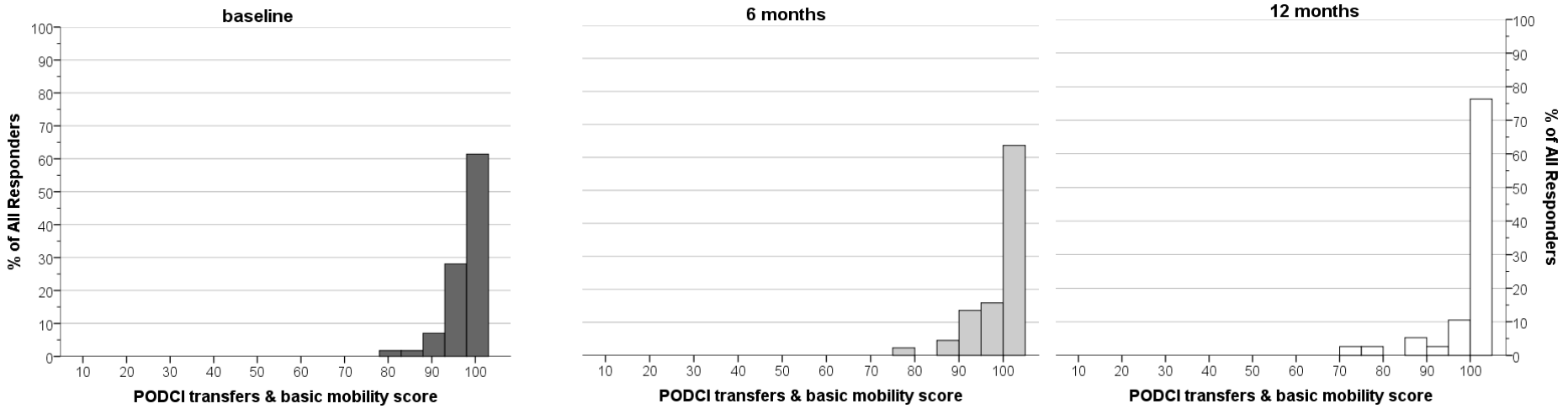


Figure 10.62 PODCI transfers & basic mobility - 12 mth Completers only histograms

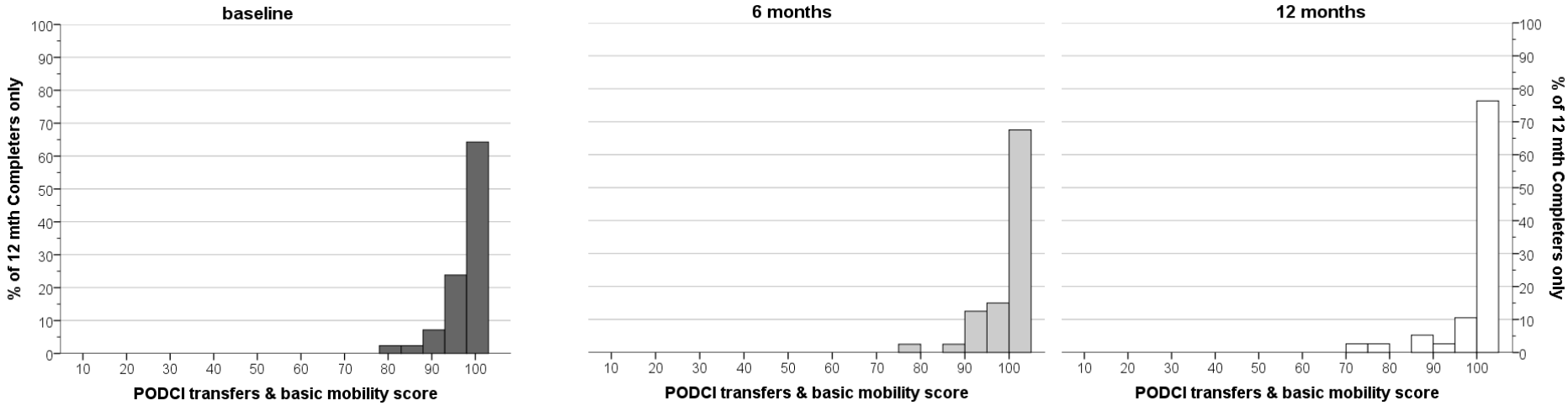


Figure 10.63 PODCI transfers & basic mobility - boxplots

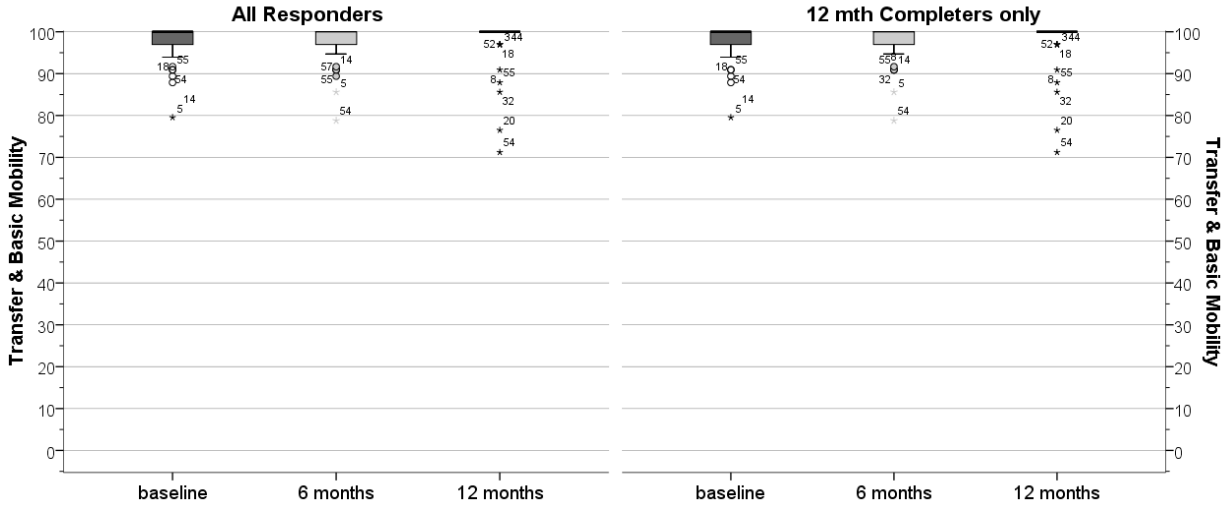


Figure 10.64 PODCI transfers & basic mobility - means (95% CI)

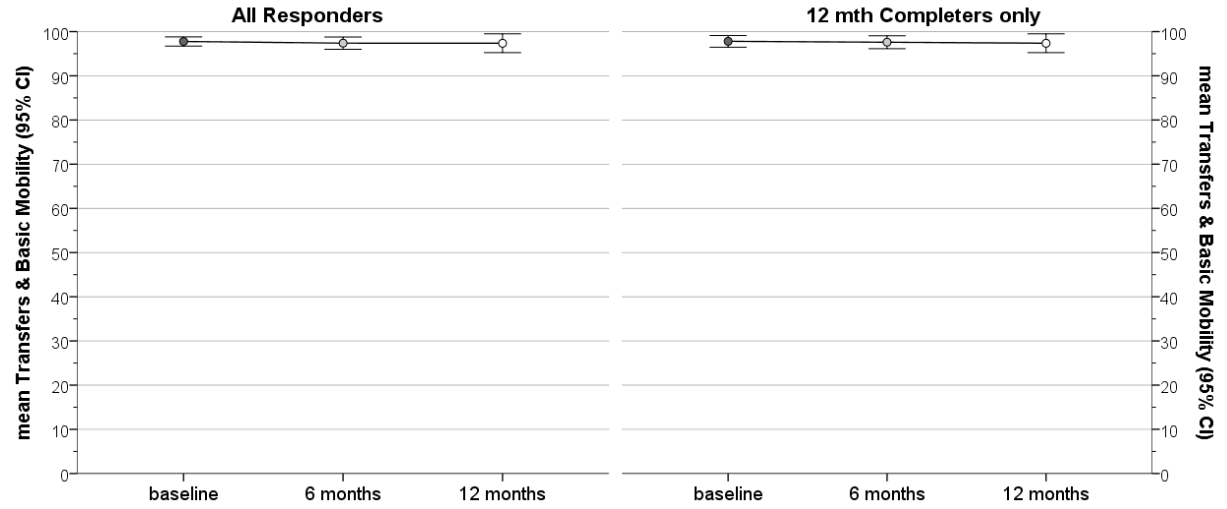


Figure 10.65 PODCI sport & physical functioning - All Responders histograms

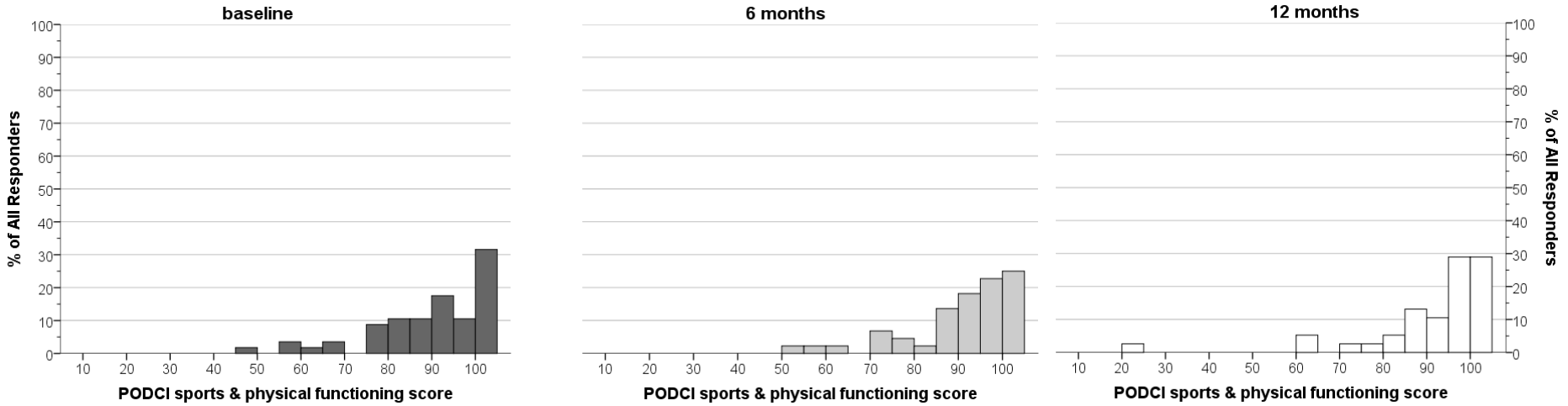


Figure 10.66 PODCI sport & physical functioning - 12 mth Completers only histograms

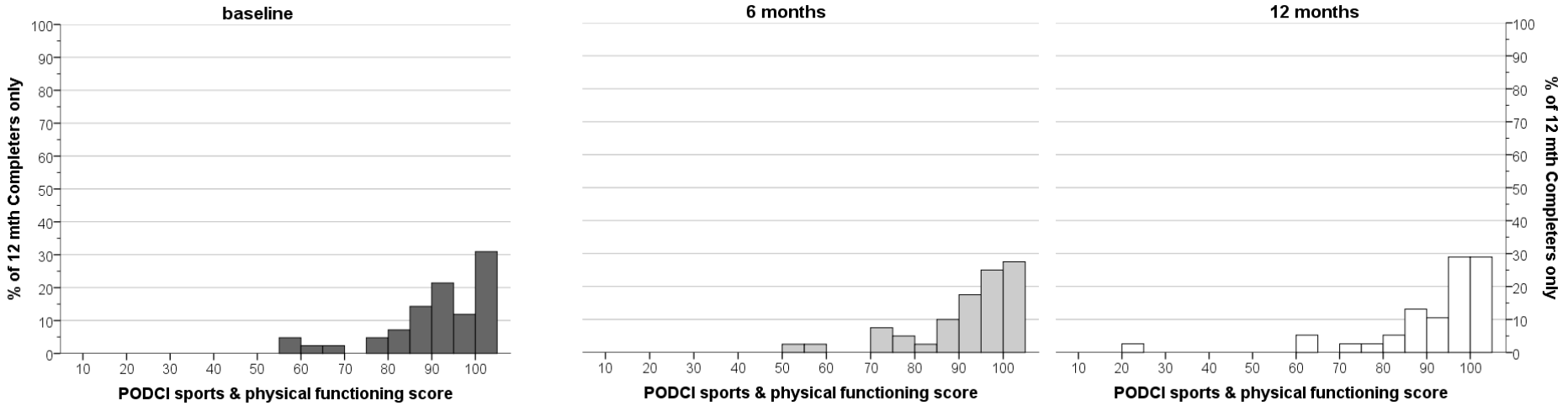


Figure 10.67 PODCI Sports & physical functioning scores - boxplots

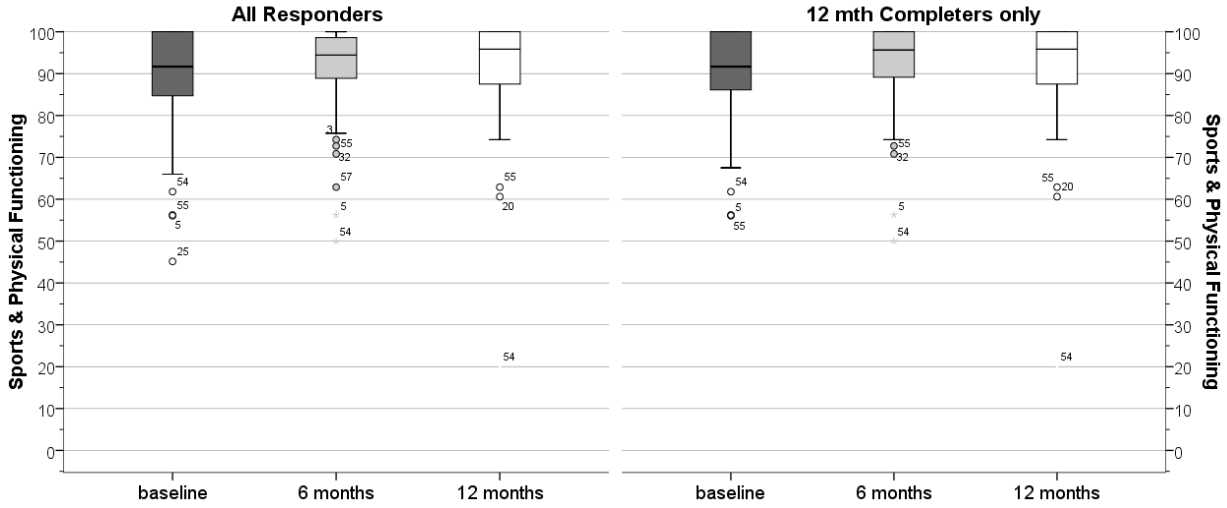


Figure 10.68 PODCI Sports & physical functioning scores - means (95% CI)

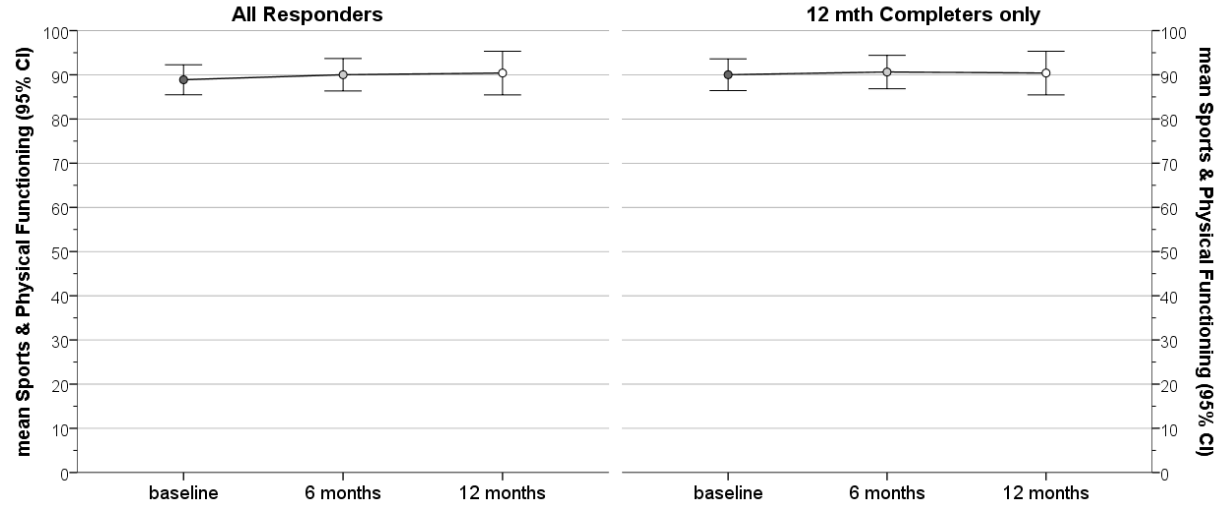


Figure 10.69 PODCI pain comfort - All Responders histograms

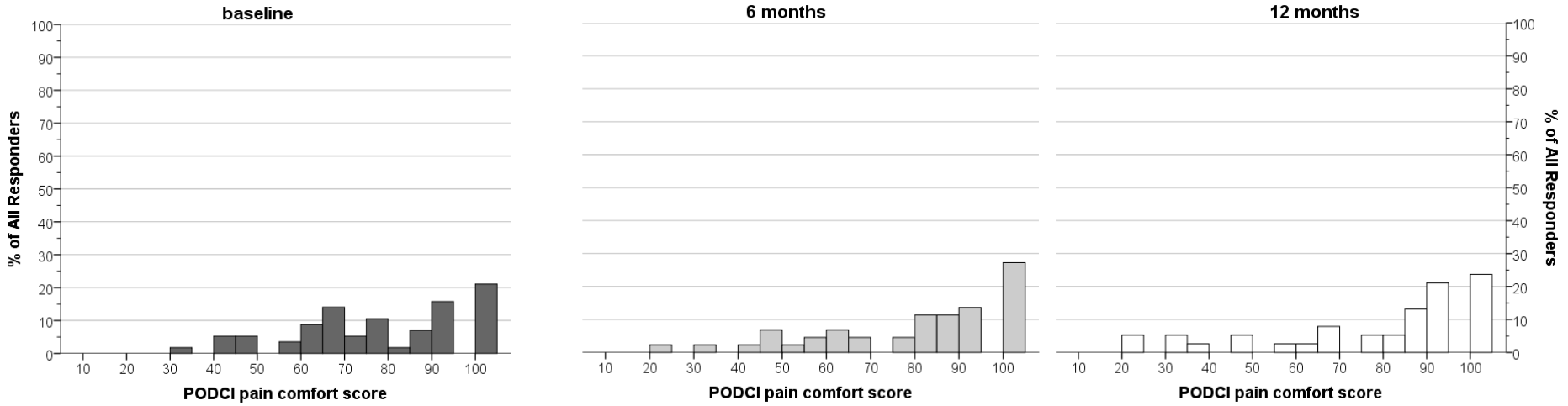


Figure 10.70 PODCI pain comfort - 12 mth Completers only histograms

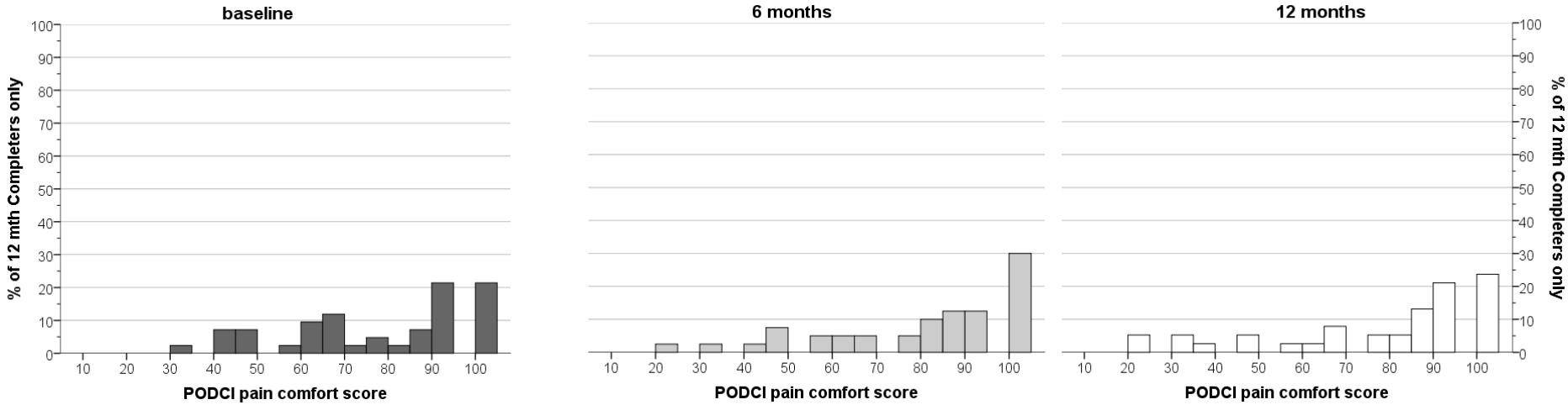


Figure 10.71 PODCI Pain/comfort scores - boxplots

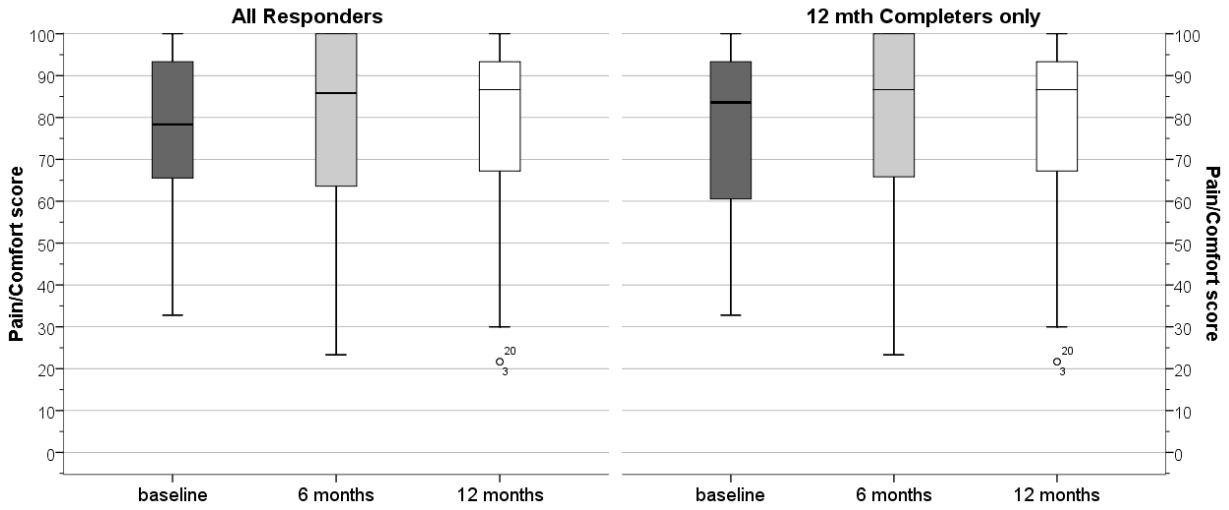


Figure 10.72 PODCI Pain/comfort scores - means (95% CI)

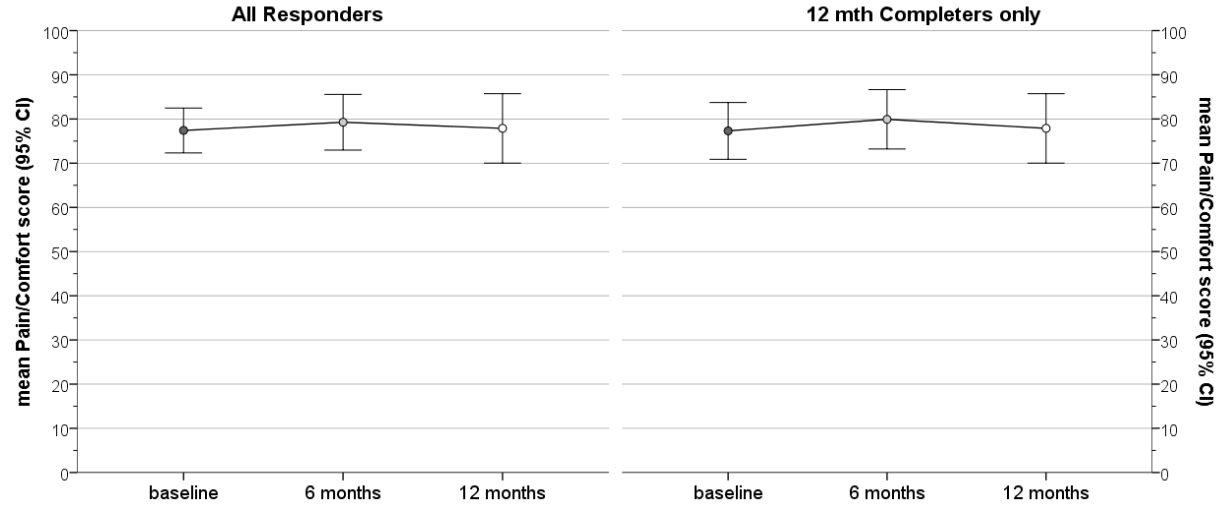


Figure 10.73 PODCI global function - All Responders histograms

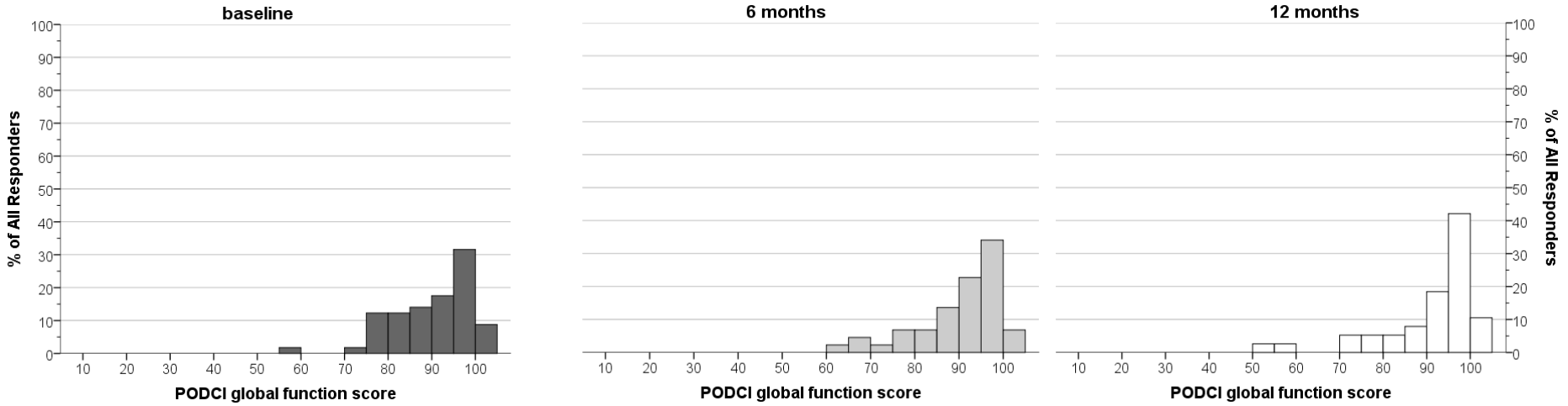


Figure 10.74 PODCI global function - 12 mth Completers only histograms

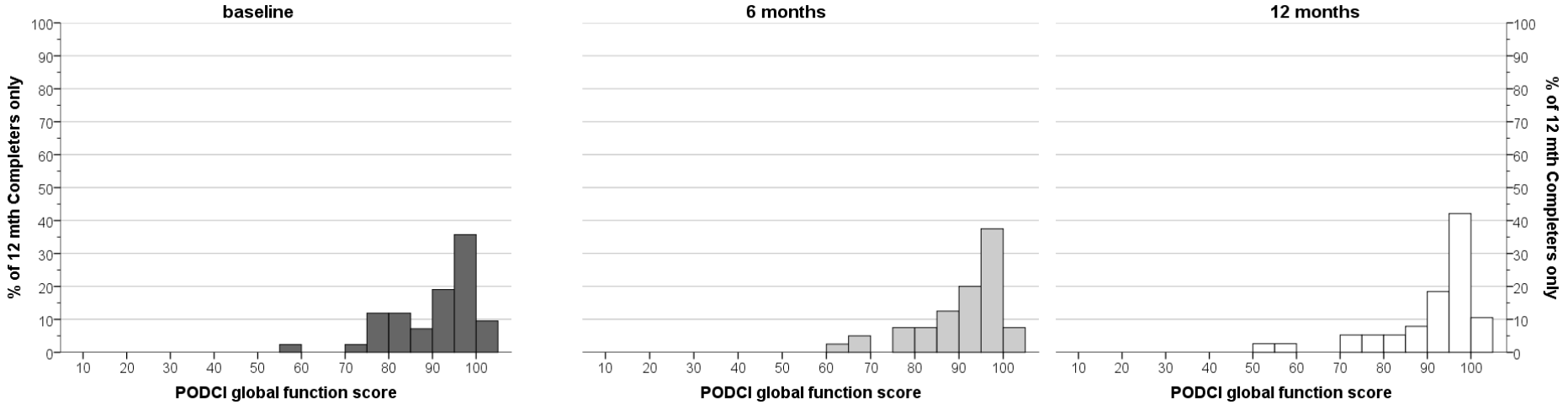


Figure 10.75 PODCI Global function score - boxplots

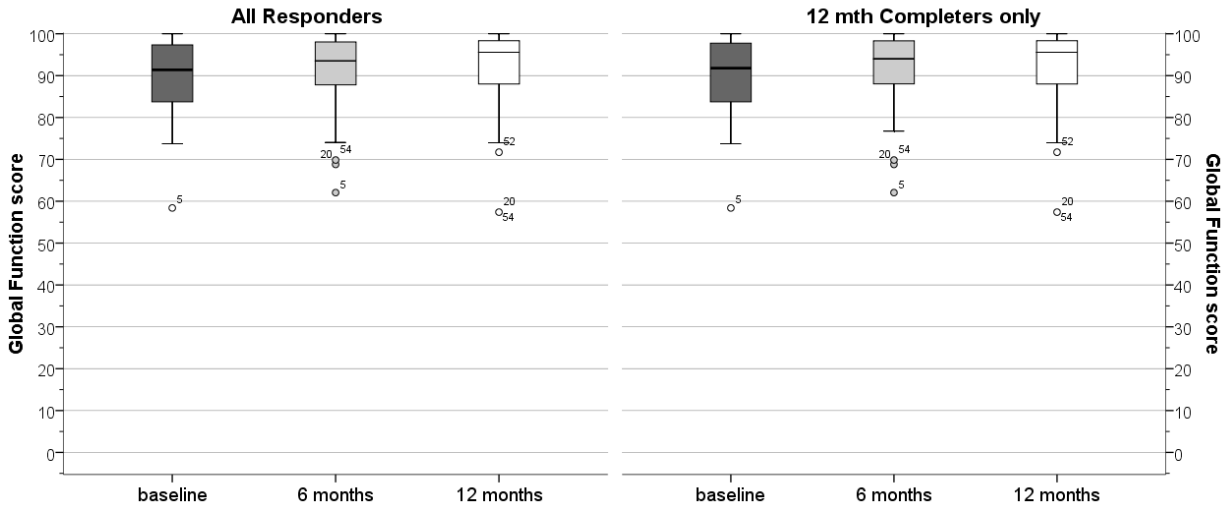


Figure 10.76 PODCI Global function score - means (95% CI)

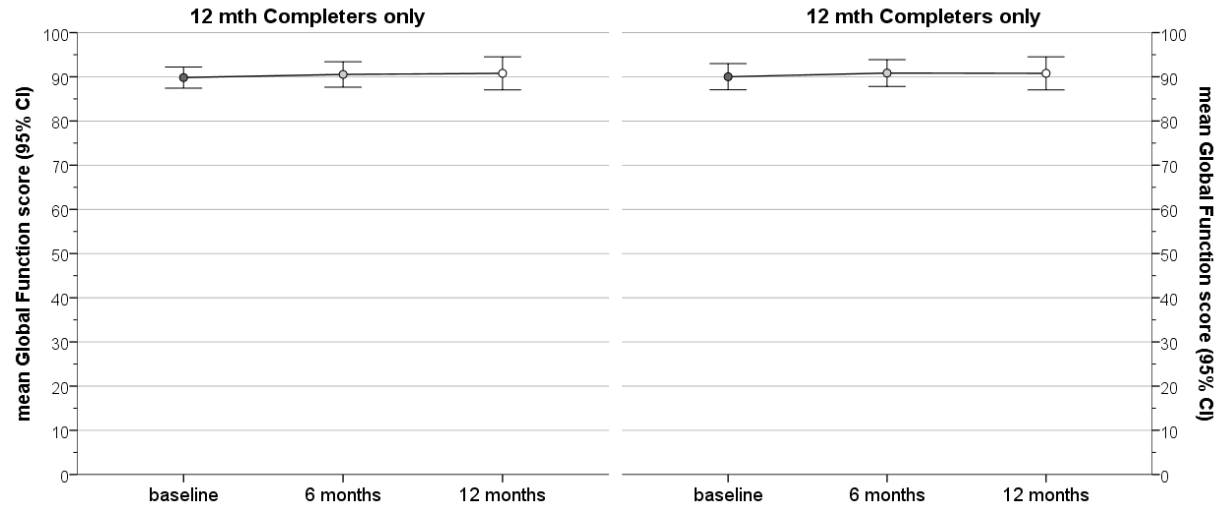


Figure 10.77 PODCI happiness - All Responders histograms

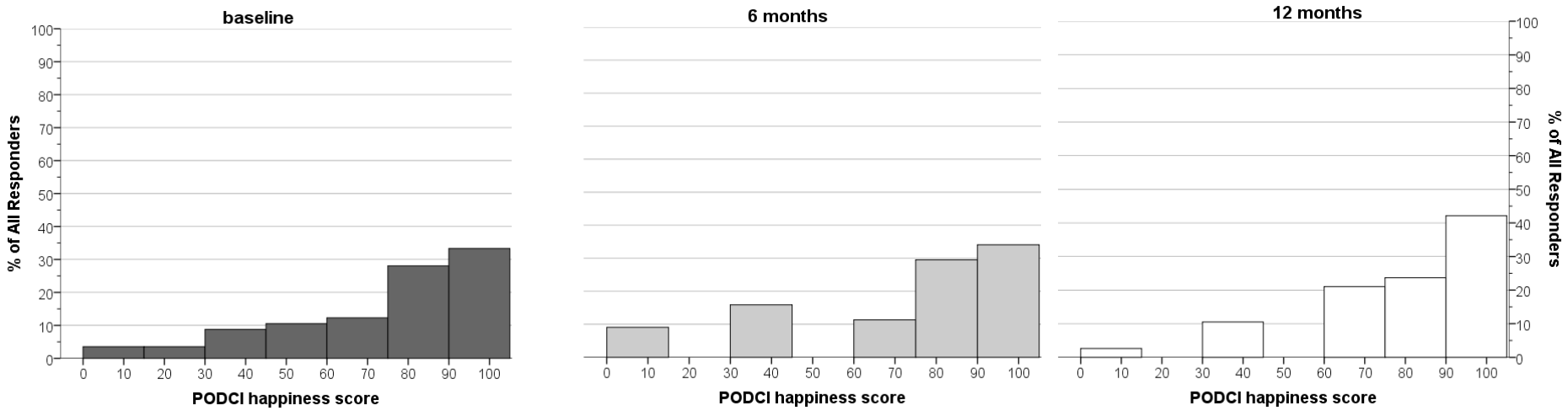


Figure 10.78 PODCI happiness - 12 mth Completers only histograms

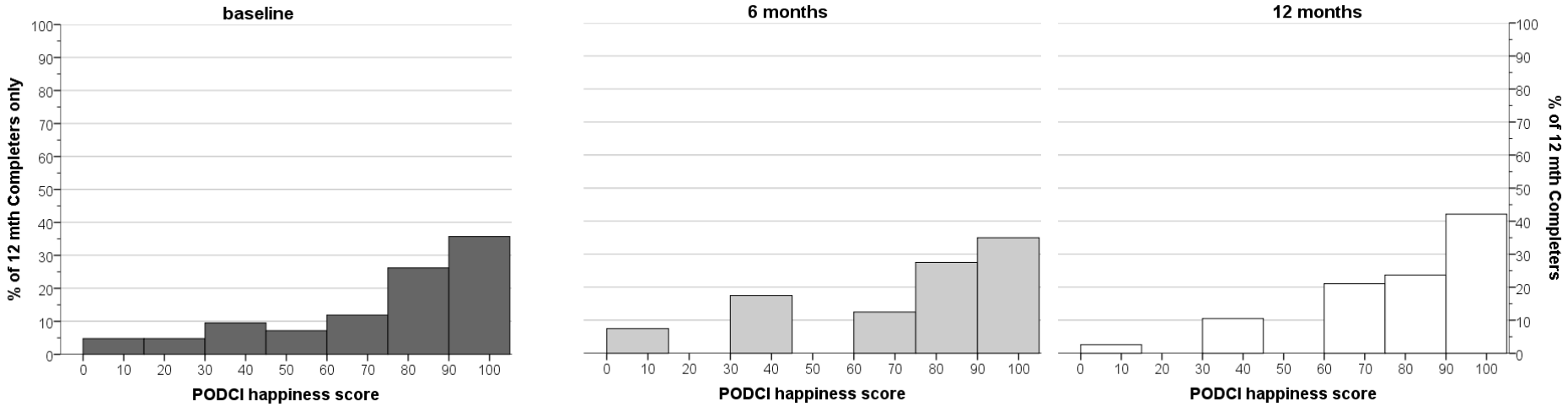


Figure 10.79 PODCI Happiness score - boxplots

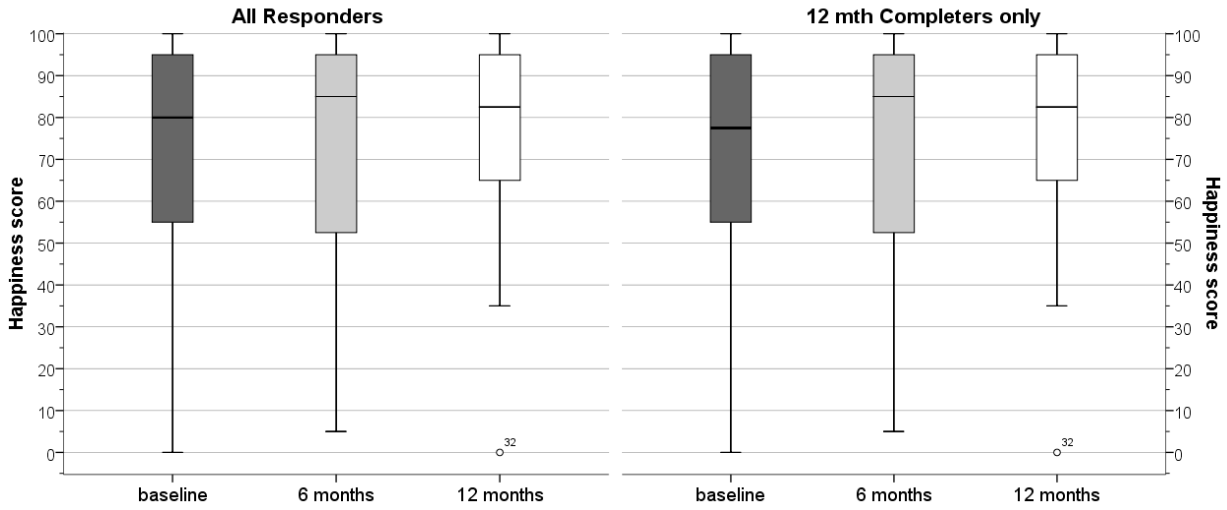
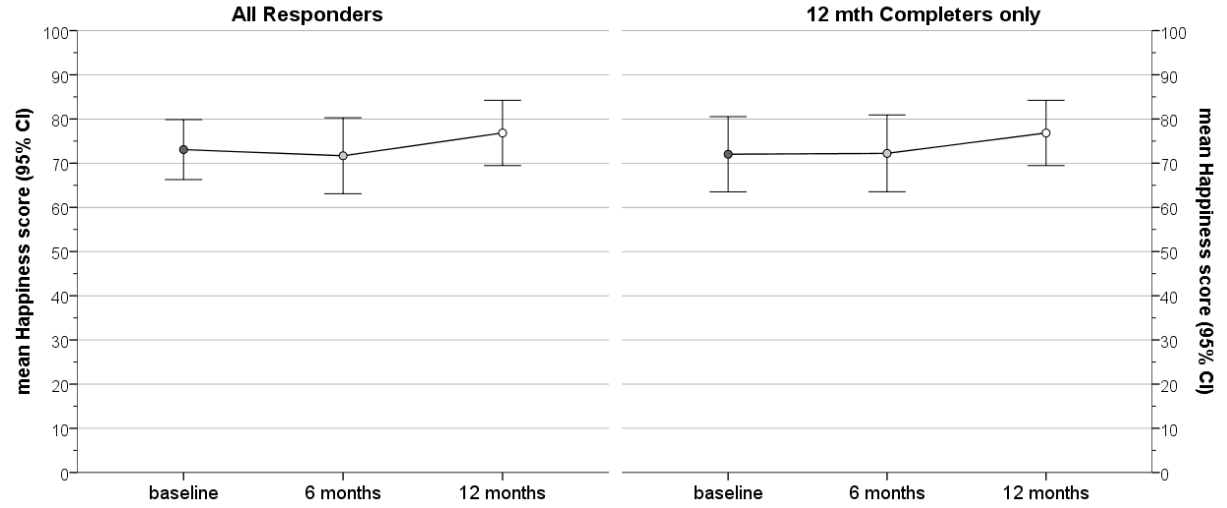


Figure 10.80 PODCI Happiness score - means (95% CI)



10.4 Physical measures of body schema

10.4.1 Two point discrimination

Descriptive statistics are presented in Table 10.30 and illustrated in Figure 10.81 to Figure 10.83. In general, there was a decrease in TPDT from baseline to 6 and 12 month follow-ups. Due to lack of normality, data was transformed (square-root) prior to testing. Statistical analysis revealed a statistically significant main effect of time-point ($F(2, 42) = 7.12$; $p=0.002$; $\eta^2=.253$) (Table 10.31). Contrasts revealed that TPDT at baseline was greater than at 6 months ($F(1, 21) = 8.71$; $p=.003$; $\eta^2=.354$) and 12 months ($F(1, 21) = 4.14$; $p=.018$; $\eta^2=.240$).

There was no statistically significant interaction between time-point and arm.

Table 10.30 TPDT - descriptive statistics

Two point discrimination threshold (mm)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=47)	49.10	13.25	1.93	45.20, 52.99	47.50	37.5, 60	27.50	75.00	11 (19.0)
	C (n=34)	48.97	13.42	2.30	44.29, 53.65	47.50	37.5, 58.13	27.50	75.00	8 (19.0)
6 months	All (n=38)	43.95	10.34	1.68	40.55, 47.35	43.75	39.38, 50	20.00	72.50	20 (34.5)
	C (n=36)	43.75	10.53	1.76	40.19, 47.31	43.75	38.13, 50	20.00	72.50	6 (14.3)
12 months	All/C (n=28)	43.48	11.75	2.22	38.93, 48.04	43.75	35, 50	27.50	82.50	30 (51.7) / 14 (33.3)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.31 Two point discrimination threshold - statistical analyses

analysis	**n**	**interaction**	**type (ε)**	**F**	**df_M**	**df_R**	**p-value**	**effect size, η^2**
TPDT (mm)	23	timepoint	SA (.961)	7.12	2	42	.002*	0.253
		timepoint x arm		0.83			0.442	0.038

* = statistically significant; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

10.4.2 Localisation

Descriptive statistics are presented in Table 10.32 and illustrated in Figure 10.84 to Figure 10.86. Localisation ability improved on average over time. However, analysis revealed no statistically significant main effect of time-point (F(2, 42) =7.12; p=0.002; η^2=.253), nor was there a statistically significant interaction between time-point and trial arm condition (F(2, 42) =7.12; p=0.002; η^2=.253) (Table 10.33).

Table 10.32 Localisation - descriptive statistics

Localisation (number correct; max = 30)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=57)	14.21	4.54	0.60	13.01, 15.41	15.00	11, 18	4.00	25.00	1 (1.7)
	C (n=41)	14.66	4.55	0.71	13.22, 16.10	15.00	12, 18	4.00	25.00	1 (2.4)
6 months	All (n=44)	16.16	4.71	0.71	14.73, 17.59	15.50	13, 18	7.00	28.00	14 (24.1)
	C (n=40)	16.38	4.58	0.72	14.91, 17.84	16.00	13.25, 18	8.00	28.00	2 (4.8)
12 months	All/C (n=37)	16.49	5.29	0.87	14.72, 18.25	19.00	12.5, 20	6.00	25.00	21 (36.2) / 5 (11.9)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.33 Localisation - statistical analyses

analysis	**n**	**interaction**	**type (ε)**	**F**	**df_M**	**df_R**	**p-value**	**effect size, η^2**
Localisation (n correct)	35	timepoint	SA (.970)	1.79	2	66	0.174	0.052
		timepoint x arm		1.06			0.352	0.031

* = statistically significant; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

10.4.3 Laterality discrimination (left/right judgement)

10.4.3.1 Hand accuracy

Descriptive statistics are presented in Table 10.34 and illustrated in Figure 10.87 to Figure 10.89. Accuracy in left/right judgement of hand images improved over time. Statistical analysis revealed a statistically significant main effect of time-point ($F(2, 68) = 4.81$; $p=0.011$; $\eta^2=.124$) (

Table 10.37). Contrasts revealed that accuracy at baseline was less than at 6 months ($F(1, 34) = 6.52$; $p=.015$; $\eta^2=.161$) and 12 months ($F(1, 34) = 9.31$; $p=.004$; $\eta^2=.215$).

There was no statistically significant interaction between time-point and arm.

Table 10.34 Laterality discrimination Hands accuracy - descriptive statistics

Laterality discrimination - Accuracy hands (% correct)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=58)	80.00	11.44	1.50	76.99, 83.01	80.00	73.75, 86.5	47.00	100.00	0
	C (n=42)	79.98	10.96	1.69	76.56, 83.39	80.00	75, 86	47.00	100.00	0
6 months	All (n=43)	82.74	11.07	1.69	79.34, 86.15	86.00	76, 91	57.00	99.00	15(25.9)
	C (n=39)	82.92	10.86	1.74	79.40, 86.44	86.00	76, 91	57.00	99.00	3 (7.1)
12 months	All/C (n=38)	85.21	9.65	1.56	82.04, 88.38	85.50	80, 92.5	52.00	100.00	20 (34.5) / 4 (9.5)

10.4.3.2 Back accuracy

Descriptive statistics are presented in Table 10.35 and illustrated in Figure 10.90 to Figure 10.92. Accuracy for left/right judgement of back images was greater than for images of the hands on average, and a similar improvement was seen over time.

Due to the highly-skewed nature of the data (Figure 10.90), a 1-way Friedman's ANOVA was performed to assess differences between time-points. The results were statistically significant (F_r13.27, df=2, p=.001) indicating an improvement with time in left/right judgement ability (

Table 10.38). Pairwise comparisons with adjusted p-values revealed that there was a significant increase in accuracy at 12 month follow-up compared to baseline (p=.002, $r_{baseline\text{-}12mths}$=.449) and 6 months (p=.047, $r_{6mths\text{-}12mths}$=.276). There was no significant difference between baseline and 6 month follow-up scores (p=.949, $r_{baseline\text{-}6mths}$=.216).

Table 10.35 Laterality discrimination Back accuracy - descriptive statistics

Laterality discrimination - Accuracy back (% correct)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=58)	85.72	10.96	1.44	82.84, 88.61	89.00	78.75, 93.25	47.00	99.00	0
	C (n=42)	84.40	11.74	1.81	80.75, 88.06	87.50	78, 92	47.00	99.00	0
6 months	All (n=43)	87.67	10.03	1.53	84.59, 90.76	91.00	80, 96	64.00	99.00	15(25.9)
	C (n=39)	87.64	10.01	1.60	84.40, 90.89	91.00	80, 96	64.00	99.00	3 (7.1)
12 months	All/C (n=38)	91.05	8.51	1.38	88.25, 93.85	94.50	86, 97	64.00	99.00	20 (34.5) / 4 (9.5)

10.4.3.3 Hand reaction times

Descriptive statistics are presented in Table 10.36 and illustrated in Figure 10.93 to Figure 10.95. Reaction time in making correct left/right judgements of images of the hand generally improved over time. Analysis of the results revealed a statistically significant main effect of time-point ($F(2, 68) = 19.85$; $p<0.001$; $\eta^2=.369$) (

Table 10.37). Contrasts revealed that reaction time at baseline was greater than at 6 months ($F(1, 32) =27.01$; $p<0.001$; $\eta^2=.458$) and 12 months ($F(1, 32) =46.62$; $p<0.001$; $\eta^2=.593$).

There was no statistically significant interaction between time-point and arm.

10.4.3.4 Back reaction time

Descriptive statistics are presented in Table 10.36 and illustrated in Figure 10.96 to Figure 10.98. Similar trends in the data were observed for reaction times when making correct left/right movement judgements of images of the trunk. A statistically significant main effect was observed for time-point ($F(1.68, 57.09) =36.63$; $p<0.001$; $\eta^2=.519$) (

Table 10.37). Contrasts revealed that there were statistically significant differences between all time-points.

There was no statistically significant interaction between time-point and arm.

Table 10.36 Laterality discrimination reaction times - descriptive statistics

Laterality discrimination - RT hands correct (sec)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=58)	3.17	1.26	0.17	2.83, 3.50	3.07	2.52, 3.52	1.37	9.11	0
	C (n=42)	3.20	1.34	0.21	2.79, 3.62	3.07	2.58, 3.50	1.37	9.11	0
6 months	All (n=43)	2.52	0.81	0.12	2.27, 2.76	2.47	2.01, 2.94	1.16	5.73	15(25.9)
	C (n=39)	2.56	0.83	0.13	2.29, 2.83	2.47	2.05, 2.98	1.16	5.73	3 (7.1)
12 months	All/C (n=38)	2.42	0.82	0.13	2.15, 2.68	2.26	1.80, 2.80	1.11	5.47	20 (34.5) / 4 (9.5)
Laterality discrimination - RT back correct (sec)										
baseline	All (n=58)	2.11	0.70	0.92	1.93, 2.29	1.97	1.63, 2.28	1.07	4.43	0
	C (n=42)	2.09	0.67	0.10	1.88, 2.30	1.95	1.63, 2.27	1.07	4.43	0
6 months	All (n=43)	1.65	0.45	0.07	1.51, 1.79	1.58	1.34, 1.92	1.04	3.12	15(25.9)
	C (n=39)	1.66	0.46	0.07	1.51, 1.81	1.58	1.34, 1.92	1.04	3.12	3 (7.1)
12 months	All/C (n=38)	1.49	0.45	0.07	1.35, 1.64	1.38	1.24, 1.55	0.92	2.90	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.37 Laterality discrimination - statistical analyses

analysis		n	interaction	type (ε)	F	df_M	df_R	p-value	effect size, η^2
Laterality Accuracy hands (% correct)		36	timepoint	SA (.907)	4.81	2	68	.011*	0.124
			timepoint x arm		0.97			0.386	0.028
Laterality reaction time hands (msec)		36	timepoint	GG (.702)	19.85	2	68	<0.001*	0.369
			timepoint x arm		0.44			0.575	0.013
Laterality reaction time back (msec)		36	timepoint	HF (.840)	36.63	1.67	57.09	<0.001*	0.519
			timepoint x arm		1.52			0.229	0.043

* = statistically significant; GG/HF = Greenhouse Guisser/Huynh-Feldt estimate of sphericity; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

Table 10.38 Laterality discrimination Accuracy Back - statistical analysis

analysis	n	test statistic, F_r	df	p-value
Accuracy Back (% correct)	36	13.269	2	0.001

* statistically significant; F_r = Friedman's ANOVA

10.4.4 Line bisection

Descriptive statistics are presented in Table 10.39 and illustrated in Figure 10.99 to Figure 10.101. The percentage error in determining the midpoint of a line remained consistent at all three time-points. This was reflected in the results of the statistical analysis (Table 10.40) which revealed no significant main effect of time-point ($F(2, 72) = 1.00$; $p=0.374$; $\eta^2=.027$), nor an interaction between time-point and trial arm ($F(2, 72) = 0.38$; $p=.687$; $\eta^2=.01$).

Table 10.39 Line bisection testing - descriptive statistics

Line bisection (relative error, %)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=58)	2.28	0.80	0.10	2.07, 2.49	2.16	1.76, 2.66	1.03	4.77	0
	C (n=42)	2.25	0.77	0.12	2.01, 2.49	2.10	1.79, 2.82	1.03	4.61	0
6 months	All (n=44)	2.39	0.71	0.11	2.18, 2.61	2.32	1.84, 2.75	1.26	4.07	14 (24.1)
	C (n=40)	2.33	0.68	0.11	2.11, 2.55	2.25	1.80, 2.72	1.26	4.07	2 (4.8)
12 months	All/C (n=39)	2.16	0.53	0.08	1.99, 2.33	2.16	1.74, 2.56	1.27	3.37	19 (32.8) / 3 (7.1)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.40 Line bisection - statistical analysis

analysis	**n**	**interaction**	**type (ε)**	**F**	**df_M**	**df_R**	**p-value**	**effect size, η^2**
Line bisection (% error)	38	timepoint	SA (.935)	1.00	2	72	0.374	0.027
		timepoint x arm		0.38			0.687	0.01

* = statistically significant; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

10.4.5 Proprioception

Descriptive statistics are presented in Table 10.41 and illustrated in Figure 10.102 to Figure 10.104. On average, there was a slight decrease in position matching error at 12 months. However, statistical analysis revealed no significant main effect of time-point ($F(2, 70) = 2.66$; $p=0.077$; $\eta^2=.071$), nor an interaction between time-point and trial arm ($F(2, 70) = 0.03$; $p=.973$; $\eta^2=.001$) (Table 10.42).

Table 10.41 Trunk proprioception - descriptive statistics

Trunk proprioception (degrees)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=58)	10.58	5.00	0.66	9.26, 11.90	10.01	7.32, 14.01	0.00	26.26	0
	C (n=42)	10.12	5.03	0.78	8.55, 11.68	9.04	6.84, 13.77	0.00	23.41	0
6 months	All (n=44)	10.10	4.94	0.74	8.59, 11.60	10.25	5.66, 12.39	1.85	23.09	14 (24.1)
	C (n=40)	10.03	5.16	0.82	8.38, 11.68	10.25	5.56, 12.92	1.85	23.09	2 (4.8)
12 months	All/C (n=38)	8.28	4.87	0.79	6.68, 9.88	7.20	5.33, 10.15	2.86	29.33	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.42 Trunk proprioception - statistical analyses

analysis	**n**	**interaction**	**type (ε)**	**F**	**df_M**	**df_R**	**p-value**	**effect size, η^2**
Proprioception (% error)	37	timepoint	SA (.988)	2.66	2	70	0.077	0.071
		timepoint x arm		0.03			0.973	0.001

* = statistically significant; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

10.4.6 Dynamic standing balance

Descriptive statistics are presented in Table 10.43 and illustrated in Figure 10.105 to Figure 10.107. Balance remained consistent between time-points suggesting little change over time. Statistical analysis (Table 10.44) confirmed this with no significant main effect of time-point ($F(2, 70) =0.01$; $p=.993$; $\eta^2<.001$), nor an interaction between time-point and trial arm ($F(2, 70) =0.26$; $p=.769$; $\eta^2=.007$).

Table 10.43 Dynamic standing balance - descriptive statistics

Dynamic standing balance (seconds)										
time point	**status***	**mean**	**sd**	**SE**	**95% CI**	**median**	**IQR**	**min**	**max**	**missing n (%)**
baseline	All (n=58)	3.32	1.89	0.25	2.82, 3.81	2.92	1.96, 4.04	1.00	12.00	0
	C (n=42)	3.14	1.93	0.30	2.54, 3.74	2.75	1.83, 3.88	1.00	12.00	0
6 months	All (n=44)	3.18	1.52	0.23	2.71, 3.64	2.83	1.88, 4.17	1.17	7.67	14 (24.1)
	C (n=40)	3.24	1.58	0.25	2.73, 3.74	2.83	1.88, 4.29	1.17	7.67	2 (4.8)
12 months	All/C (n=38)	3.20	1.48	0.24	2.72, 3.69	2.83	2.33, 3.71	1.17	7.17	20 (34.5) / 4 (9.5)

*All = all completers at each time point; C = only those who completed 12 month follow-up

Table 10.44 Dynamic balance - statistical analyses

analysis	**n**	**interaction**	**type (ε)**	**F**	**df_M**	**df_R**	**p-value**	**effect size, η^2**
Balance (sec)	37	timepoint	SA (.876)	0.01	2	70	0.993	<0.001
		timepoint x arm		0.26			0.769	0.007

* = statistically significant; SA = sphericity assumed (Mauchly's W); dfM = degrees of freedom (main effect); dfR = degrees of freedom (error); η^2=partial eta squared

Figure 10.81 TPDT - histograms

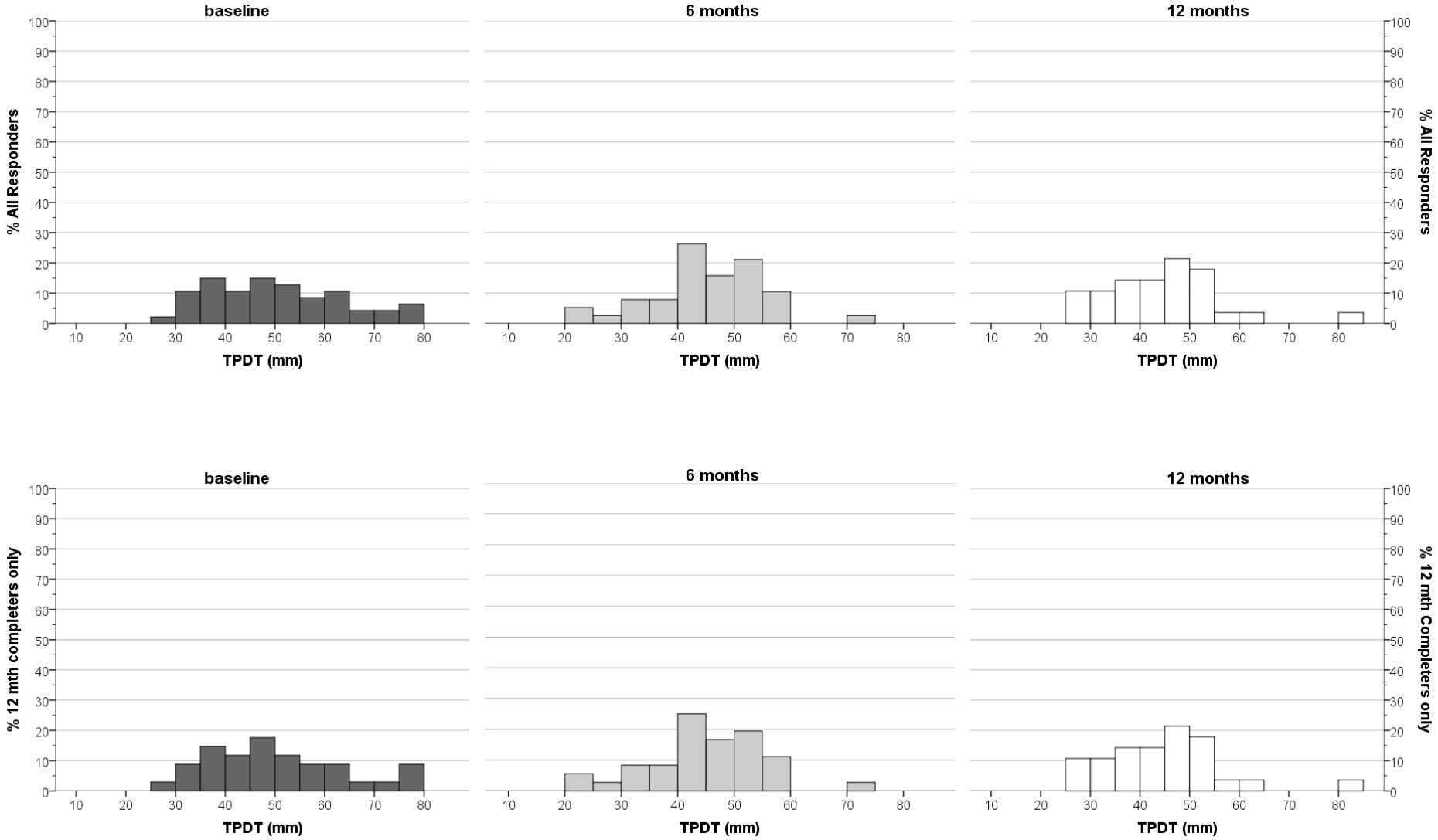


Figure 10.82 TPDT - boxplots

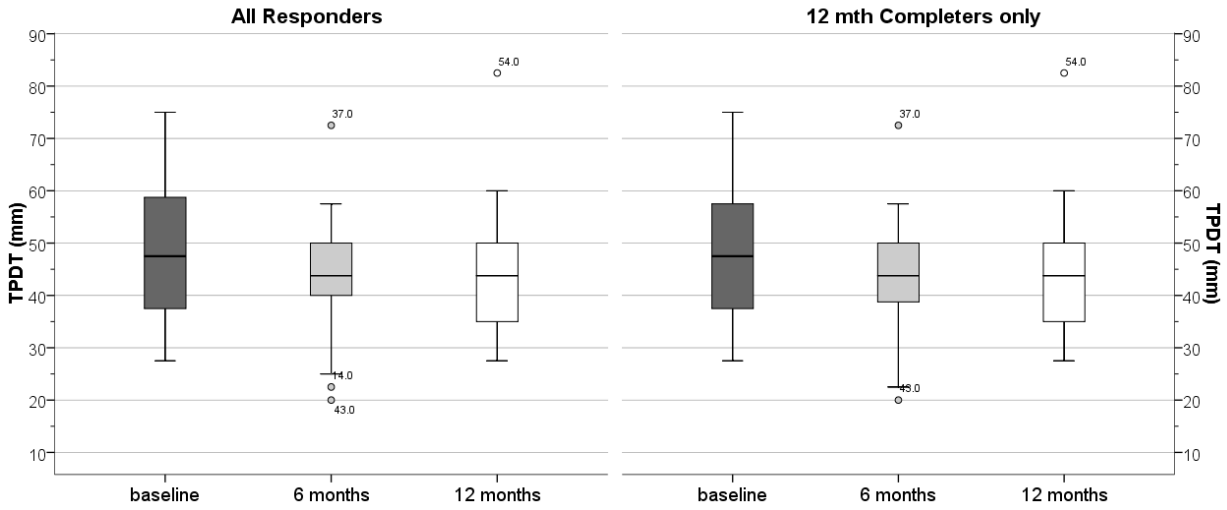


Figure 10.83 TPDT - means (95% CI)

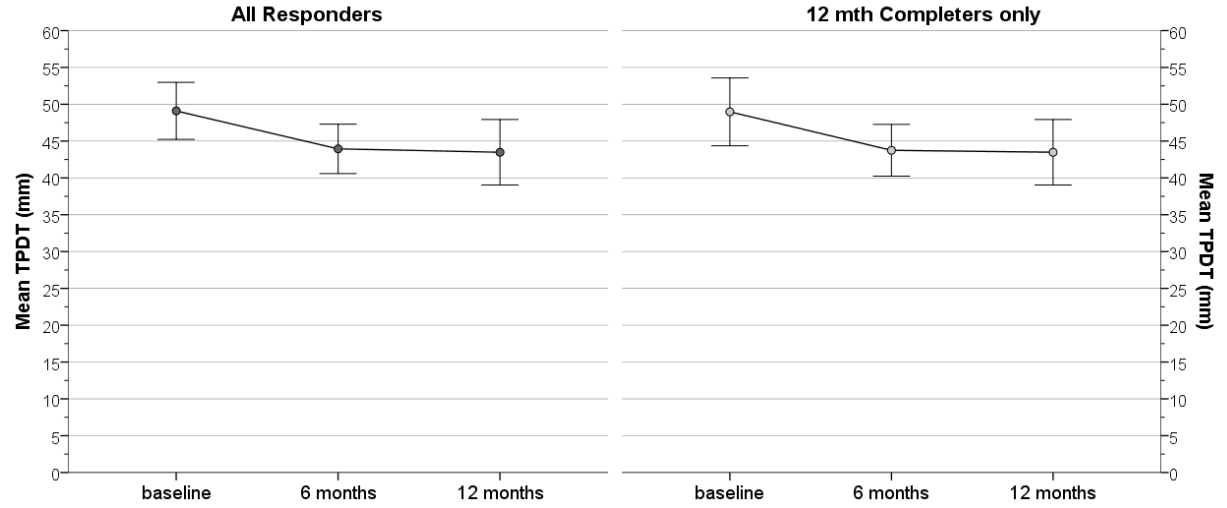


Figure 10.84 Localisation - histograms

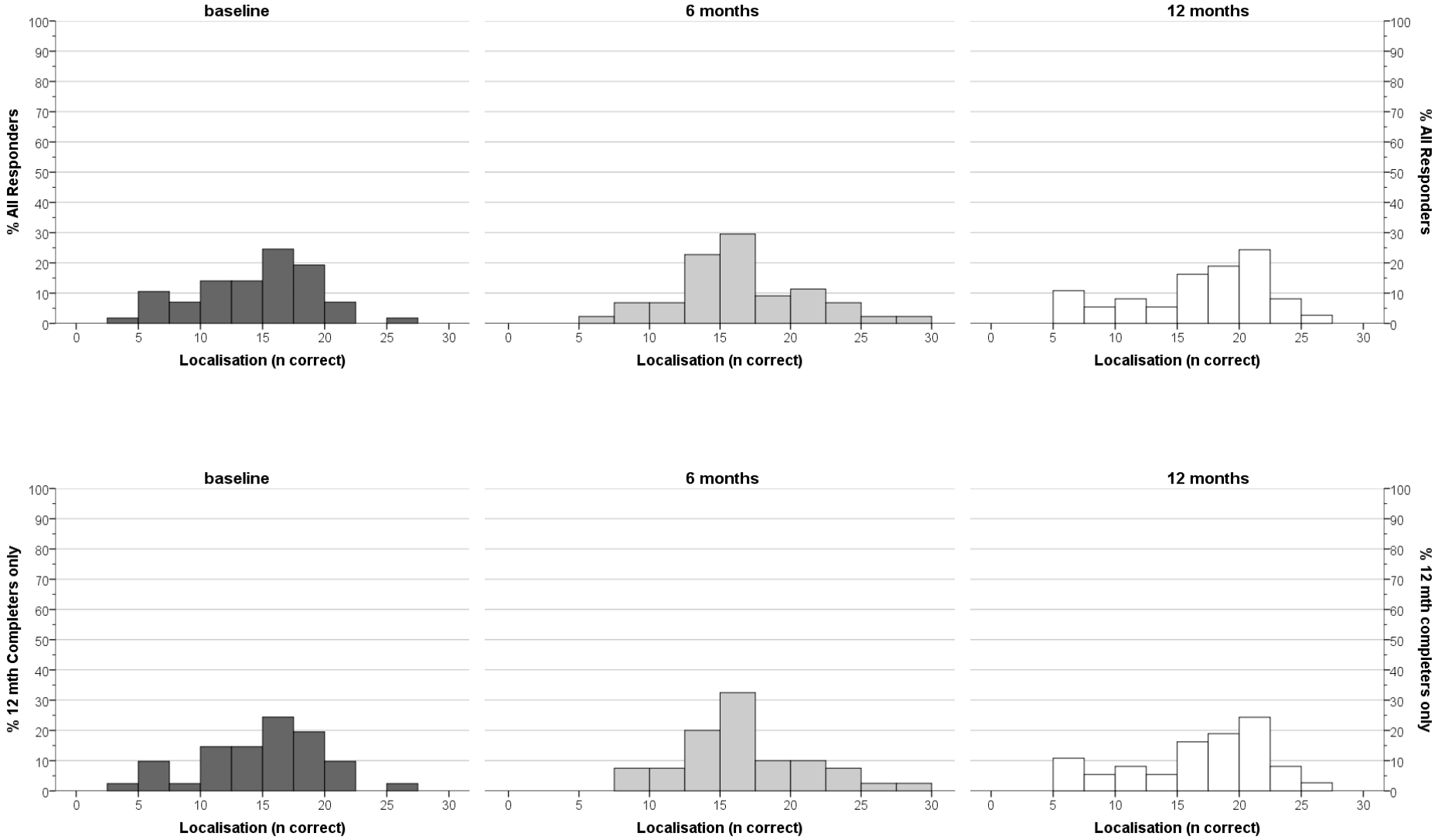


Figure 10.85 Localisation - boxplots

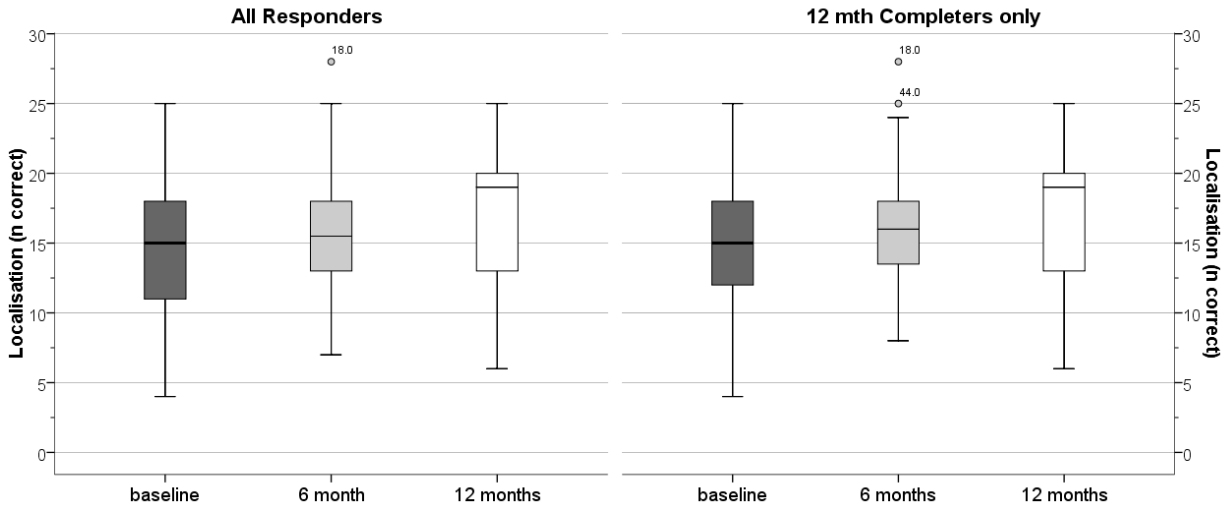


Figure 10.86 Localisation - means (95% CI)

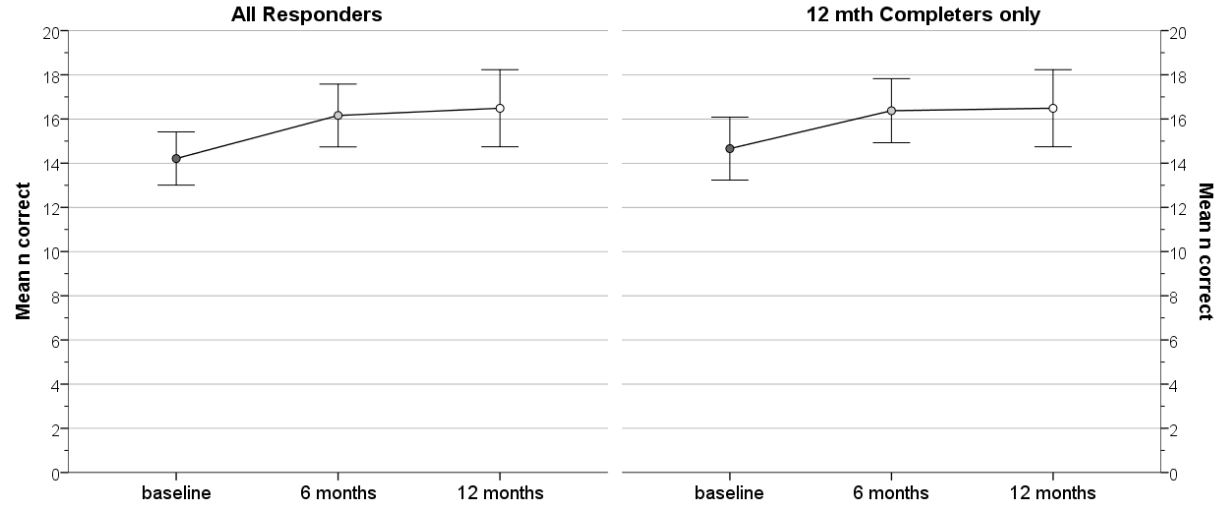


Figure 10.87 Laterality discrimination - Hands accuracy histograms

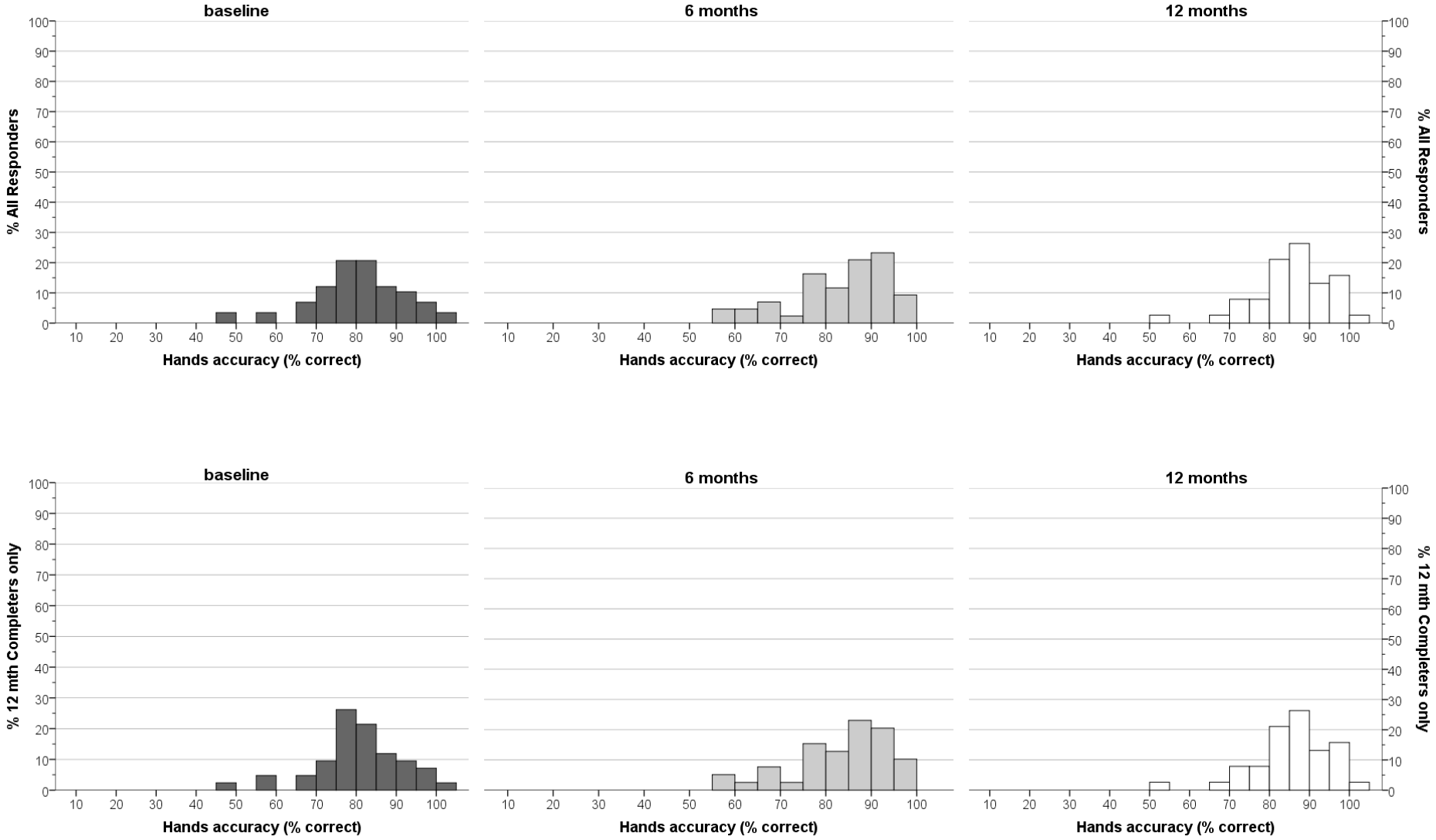


Figure 10.88 Laterality discrimination Hands accuracy - boxplots

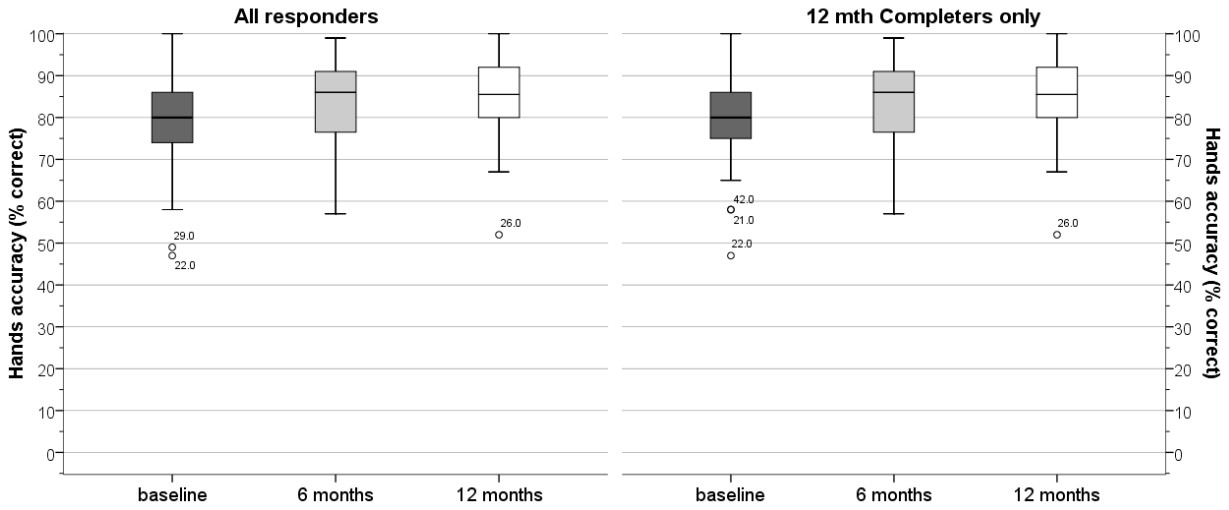


Figure 10.89 Laterality discrimination Hands accuracy - means (95% CI)

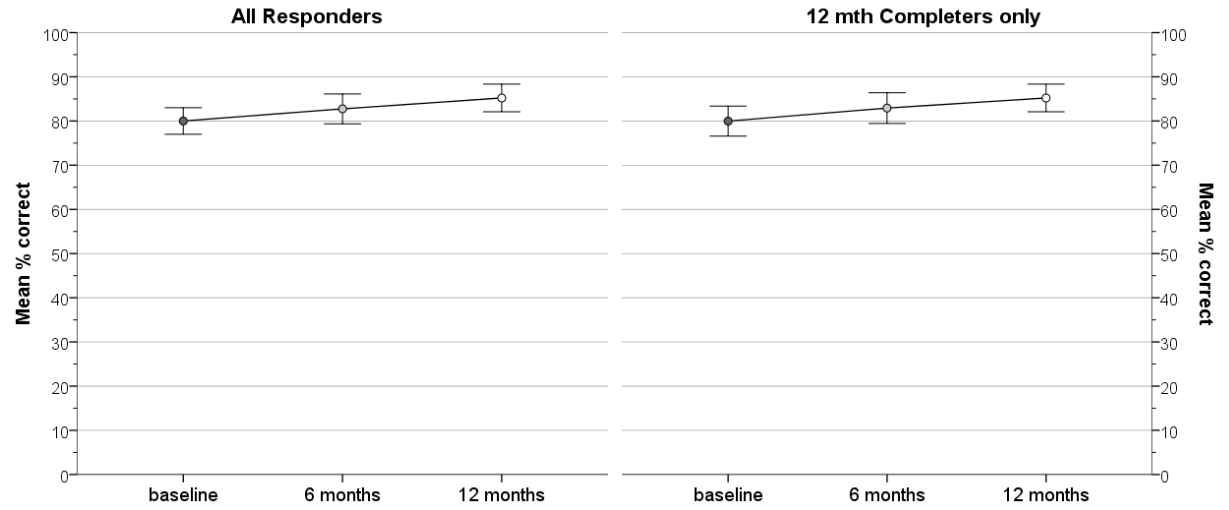


Figure 10.90 Laterality discrimination Back accuracy - histograms

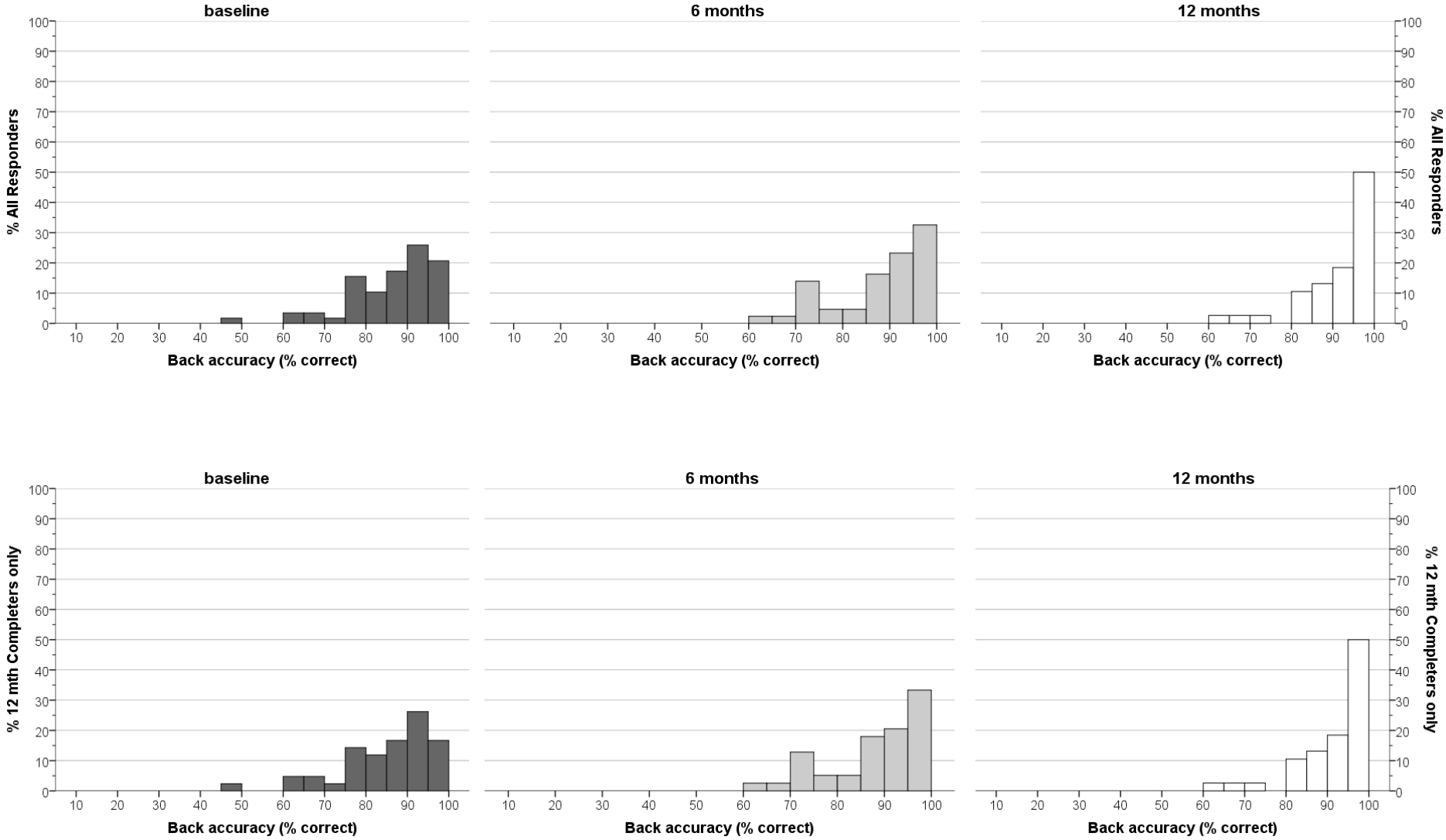


Figure 10.91 Laterality discrimination Back accuracy - boxplots

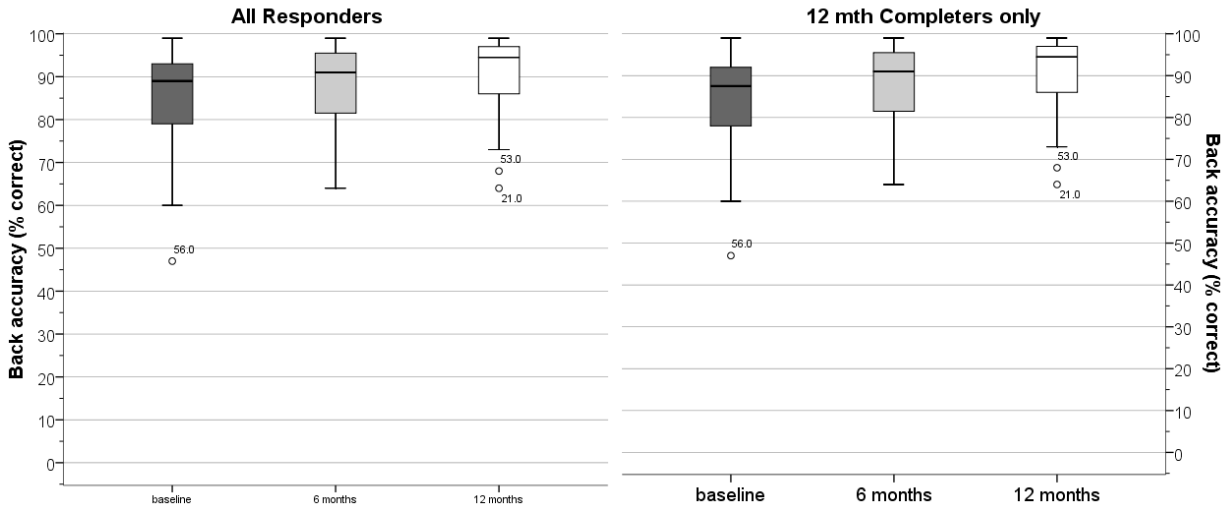


Figure 10.92 Laterality discrimination Back accuracy - means (95% CI)

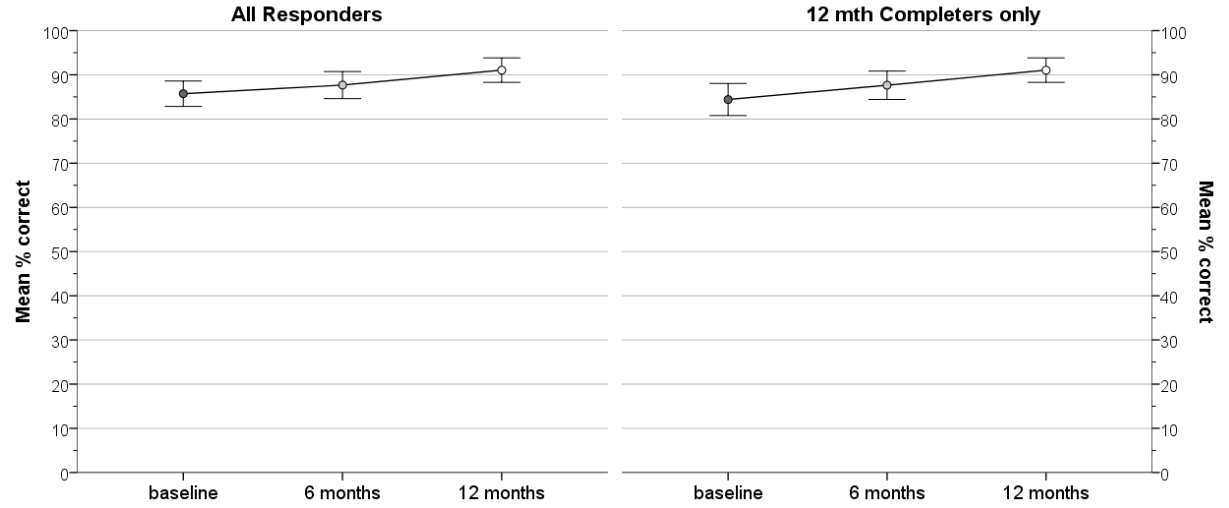


Figure 10.93 Laterality discrimination Reaction time Hands - histograms

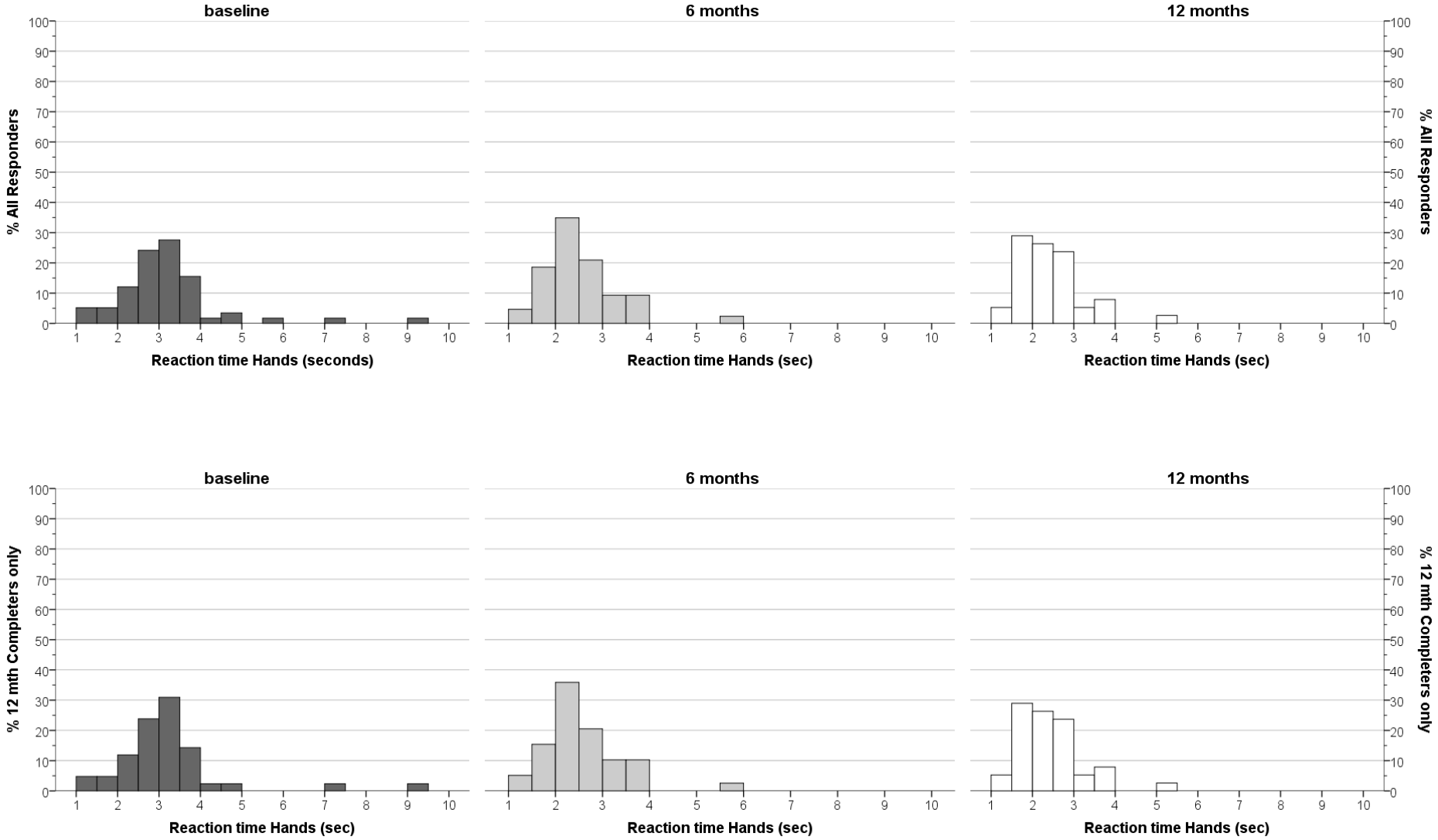


Figure 10.94 Laterality discrimination Reaction time Hands - boxplots

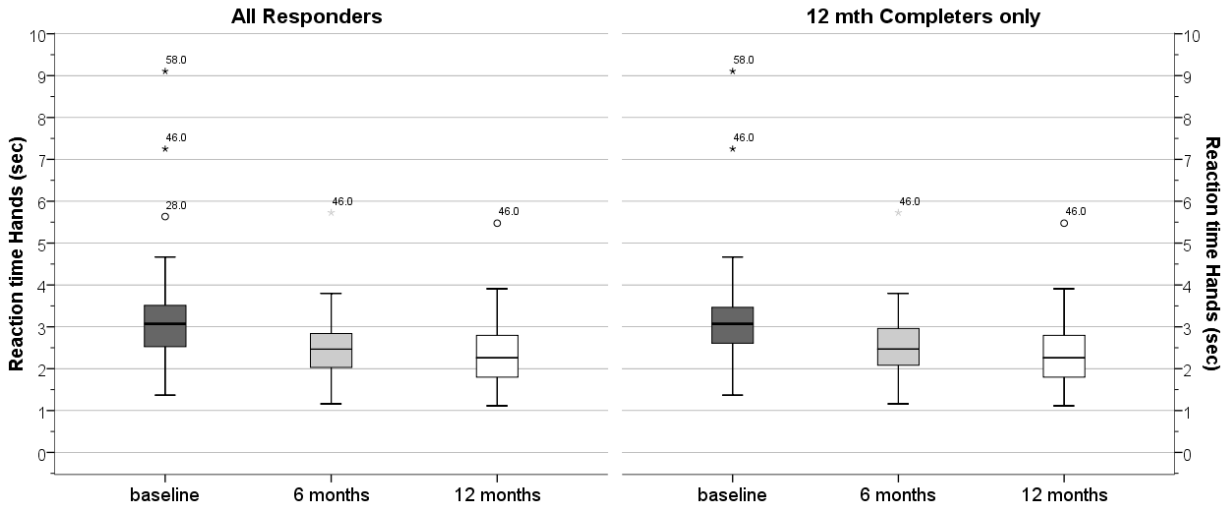


Figure 10.95 Laterality discrimination Reaction time Hands - means (95% CI)

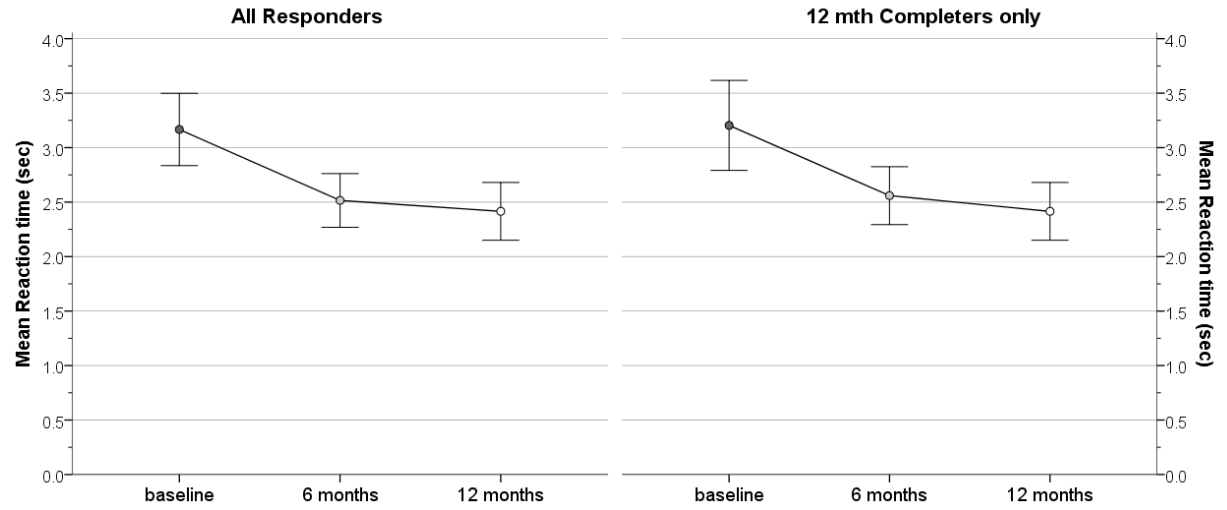


Figure 10.96 Laterality discrimination Reaction time Back - histograms

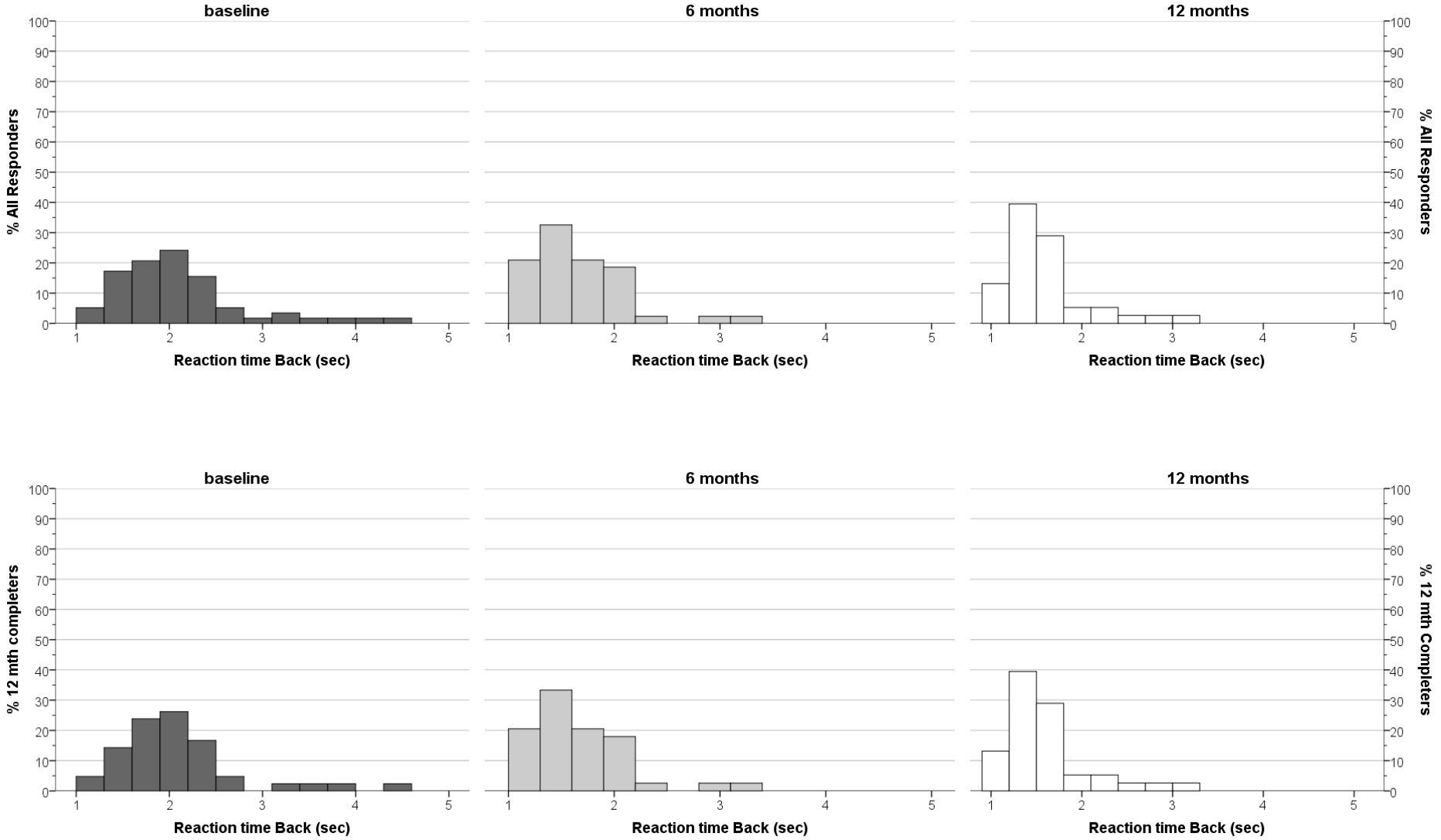


Figure 10.97 Laterality discrimination Reaction time Back - boxplots

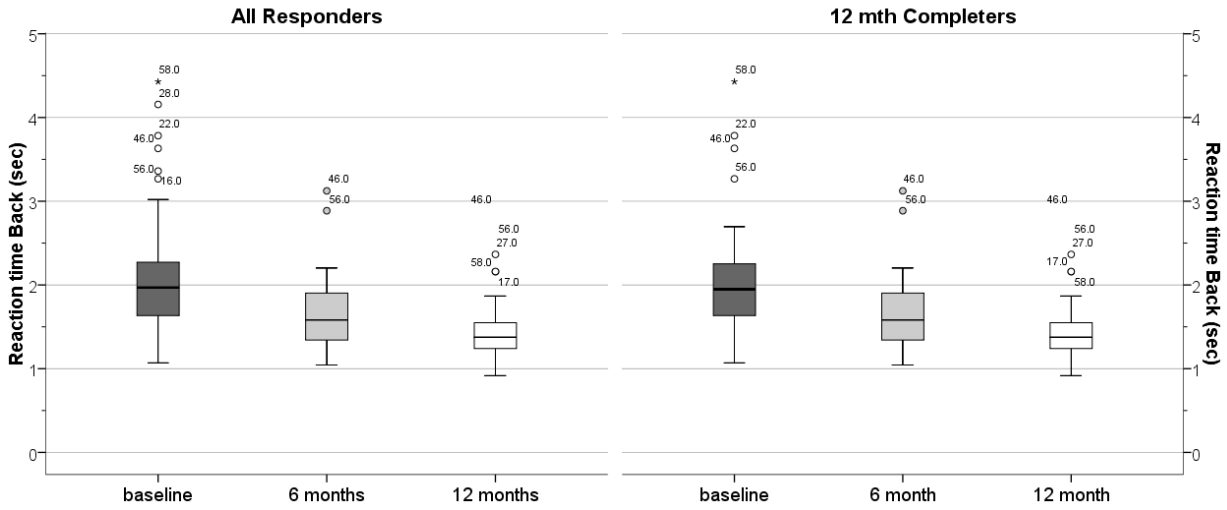


Figure 10.98 Laterality discrimination Reaction time Back - means (95% CI)

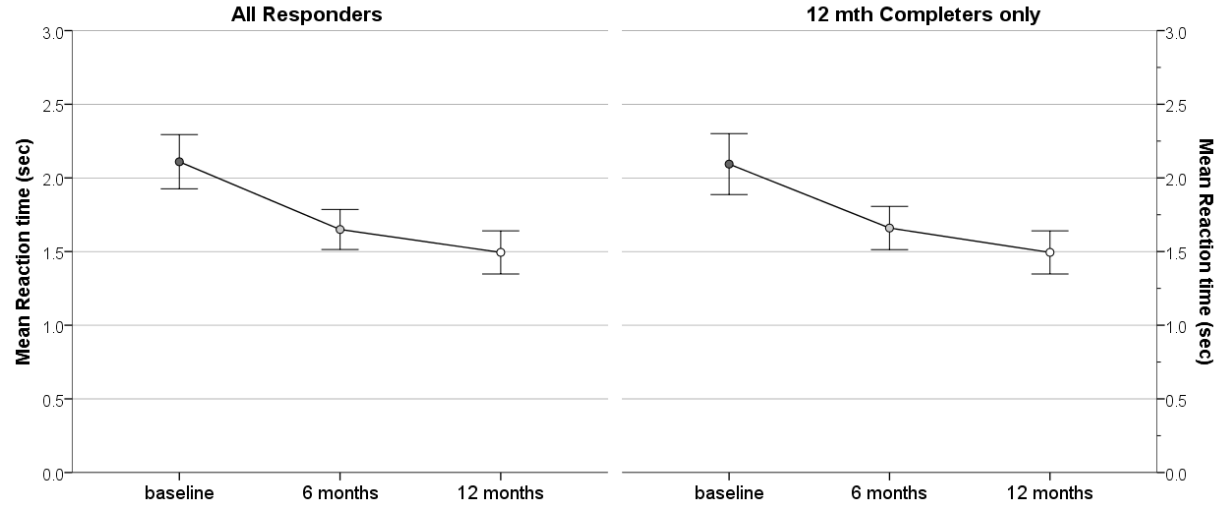


Figure 10.99 Line bisection - histograms

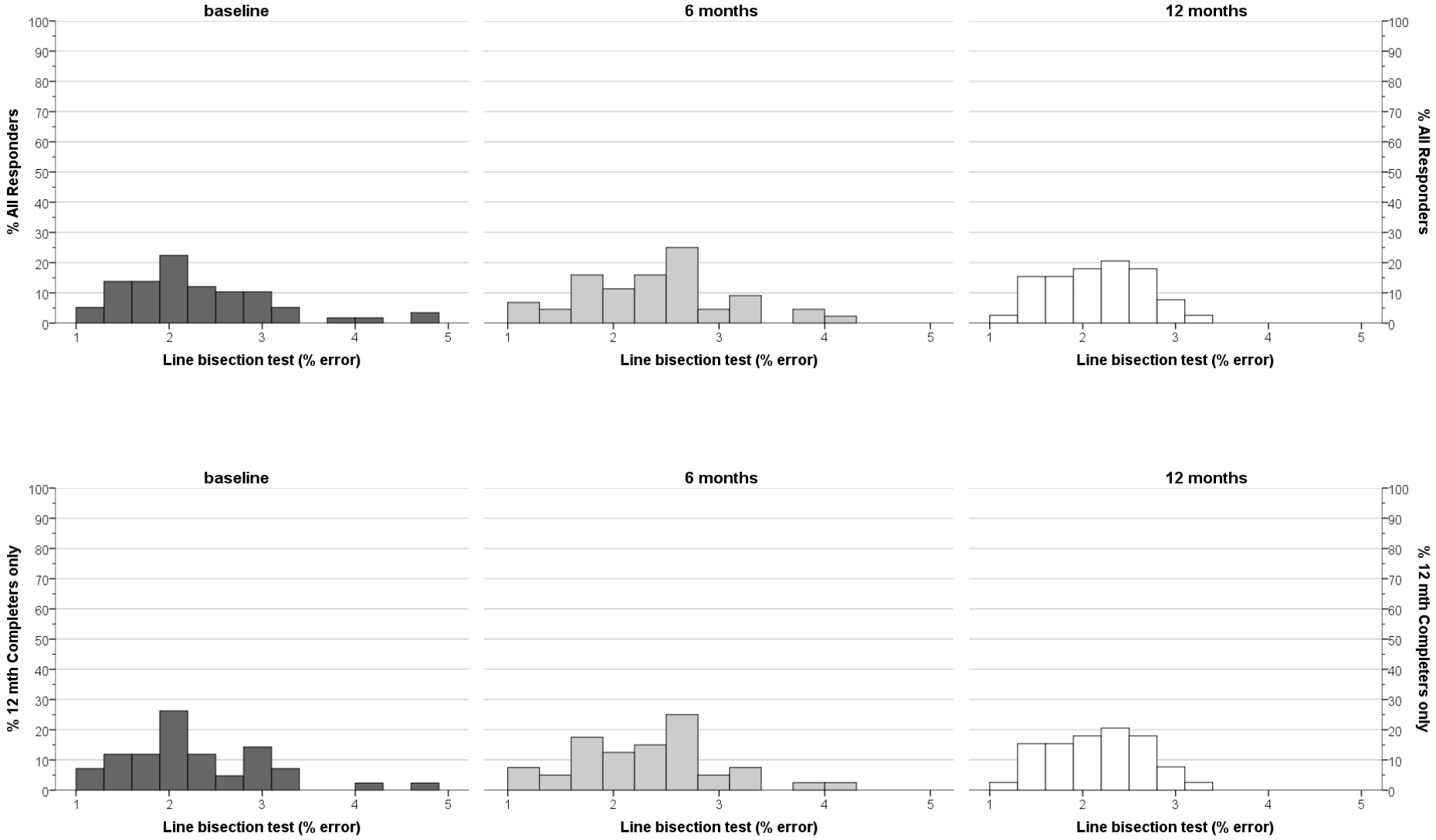


Figure 10.100 Line bisection - boxplots

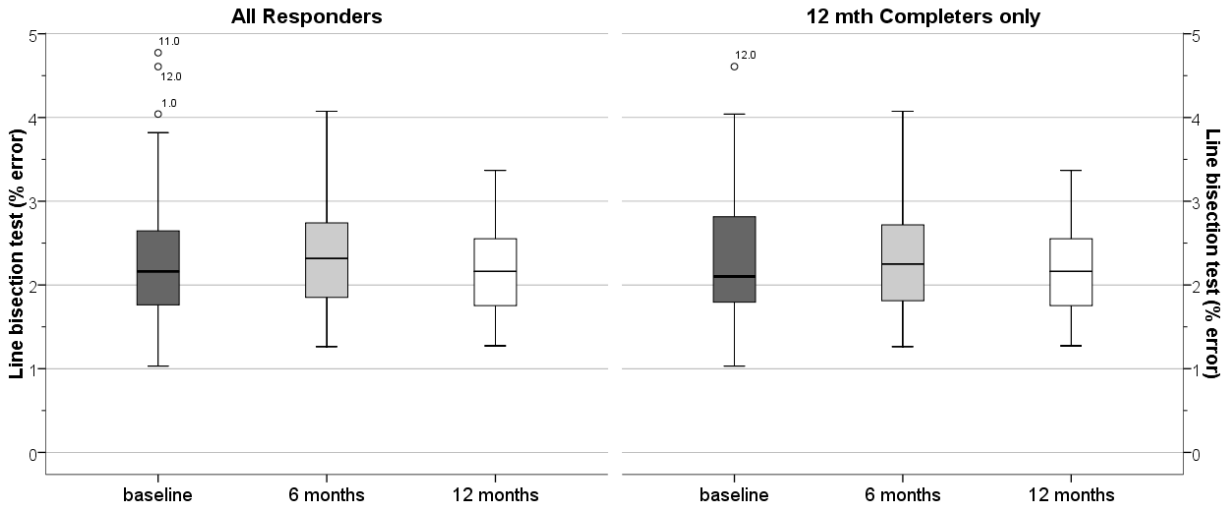


Figure 10.101 Line bisection - means (95% CI)

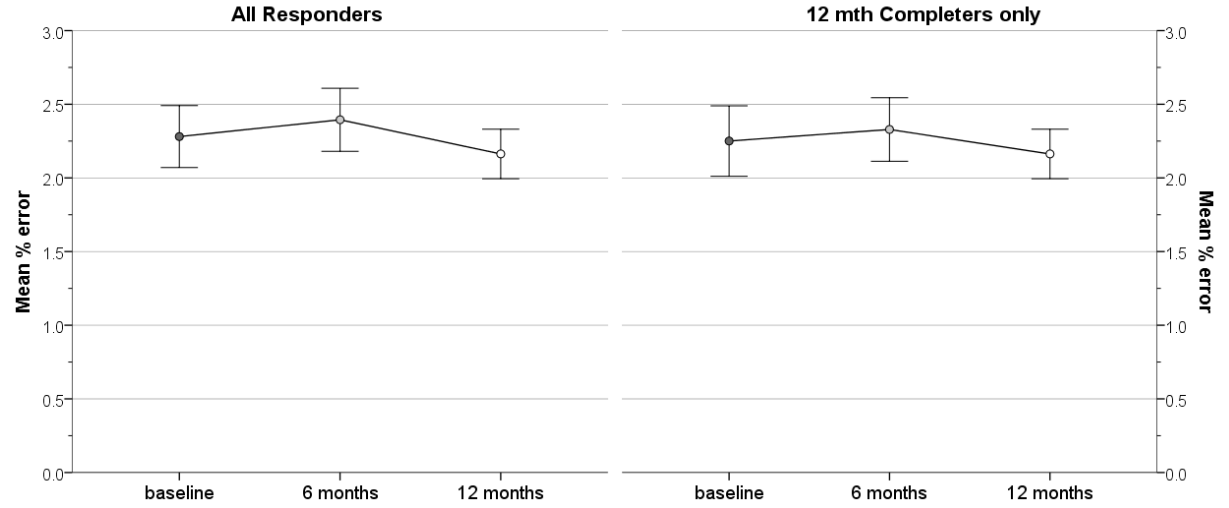


Figure 10.102 Proprioception - histograms

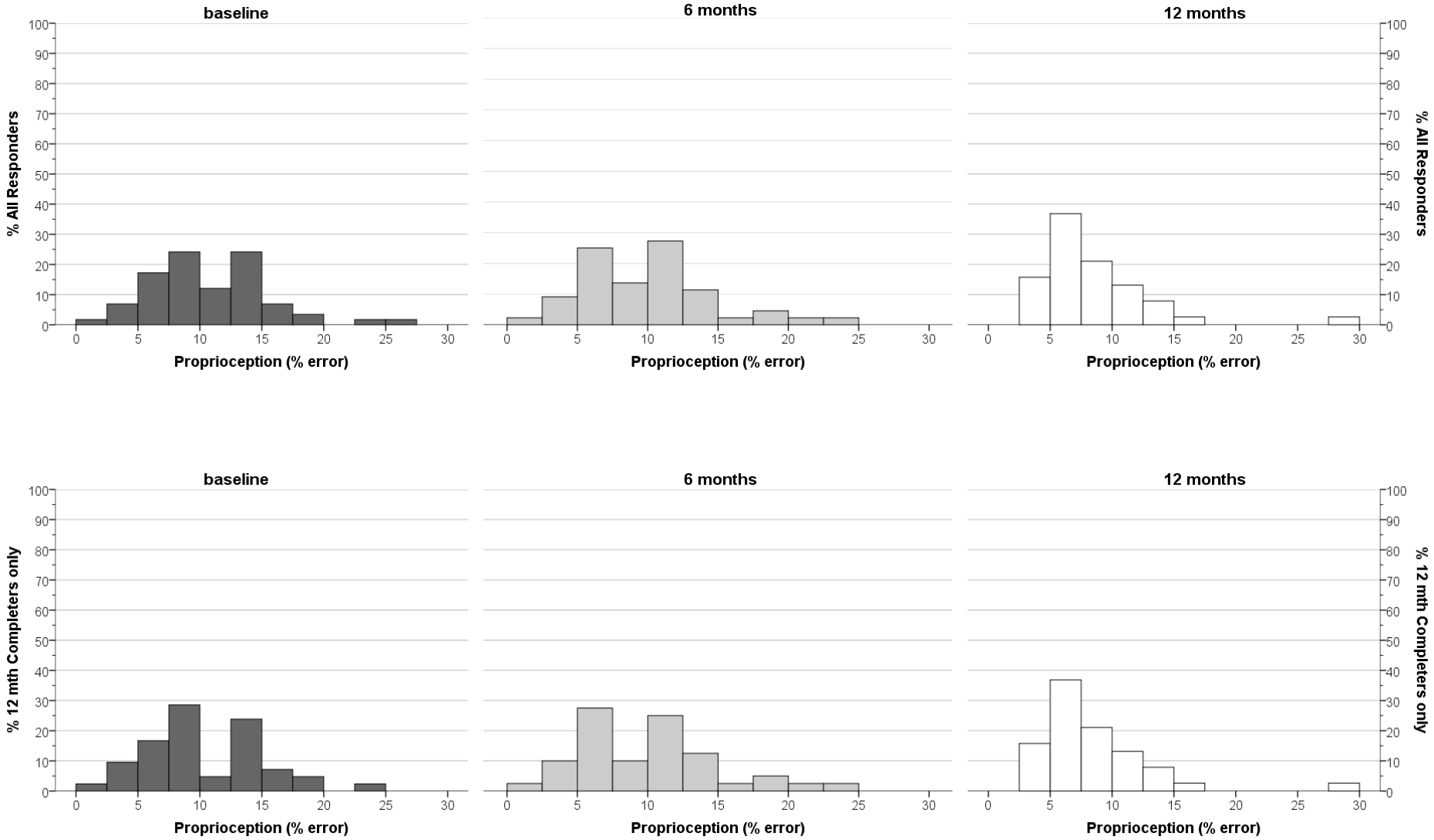


Figure 10.103 Proprioception - boxplots

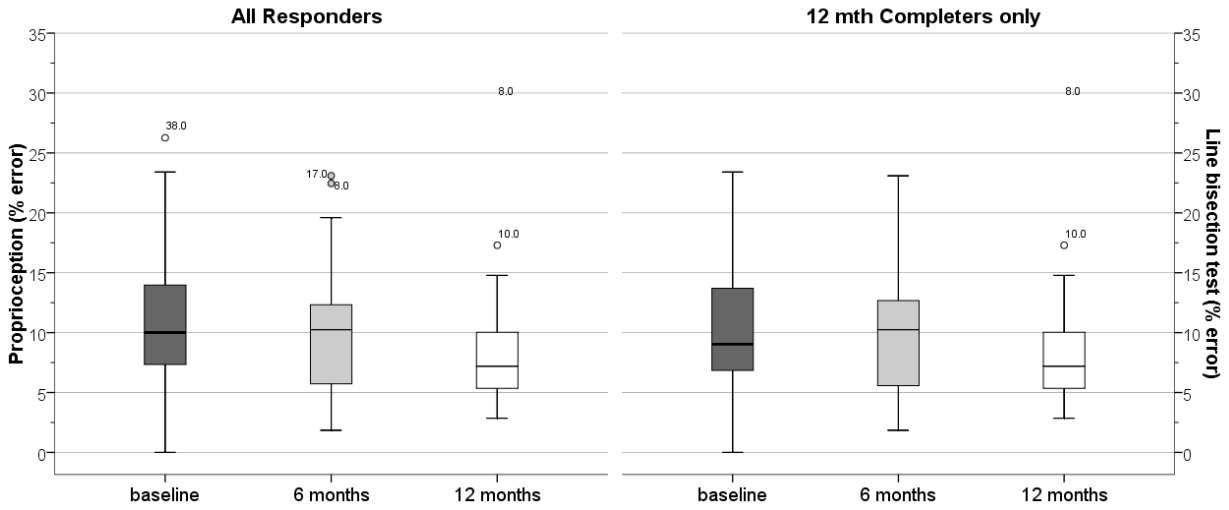


Figure 10.104 Proprioception - means (95% CI)

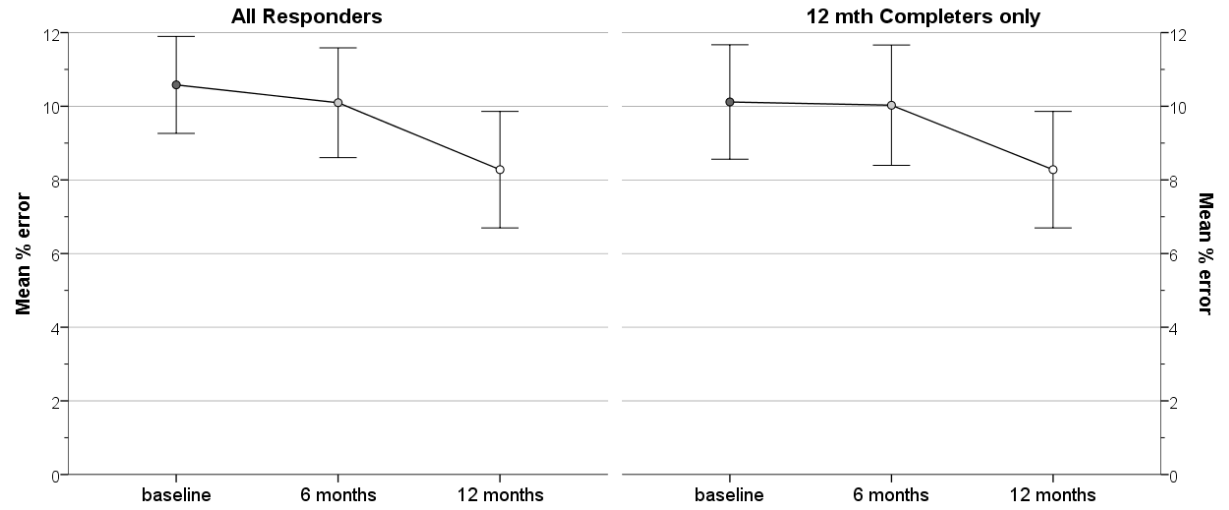


Figure 10.105 Dynamic standing balance - histograms

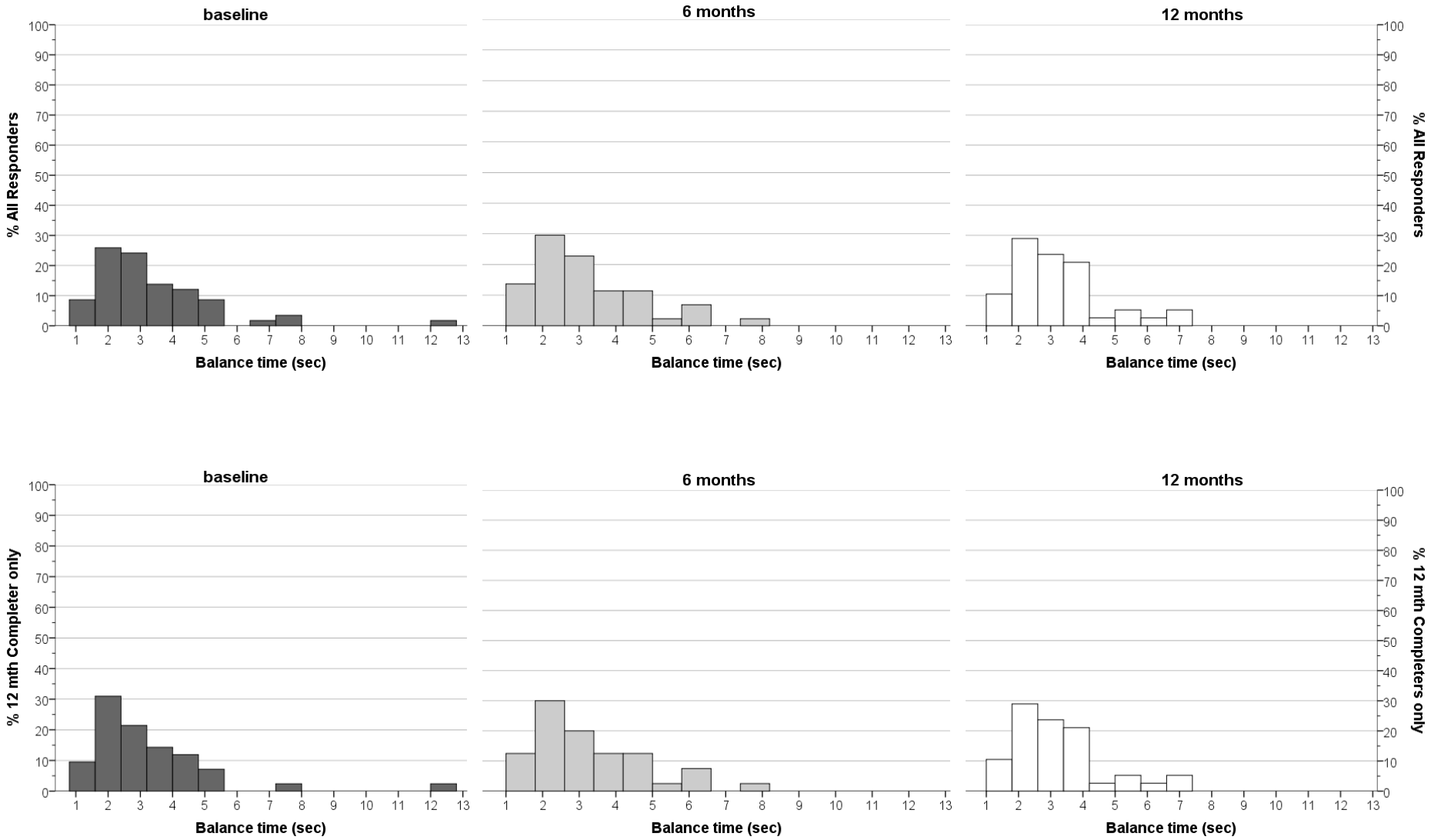


Figure 10.106 Dynamic standing balance - boxplots

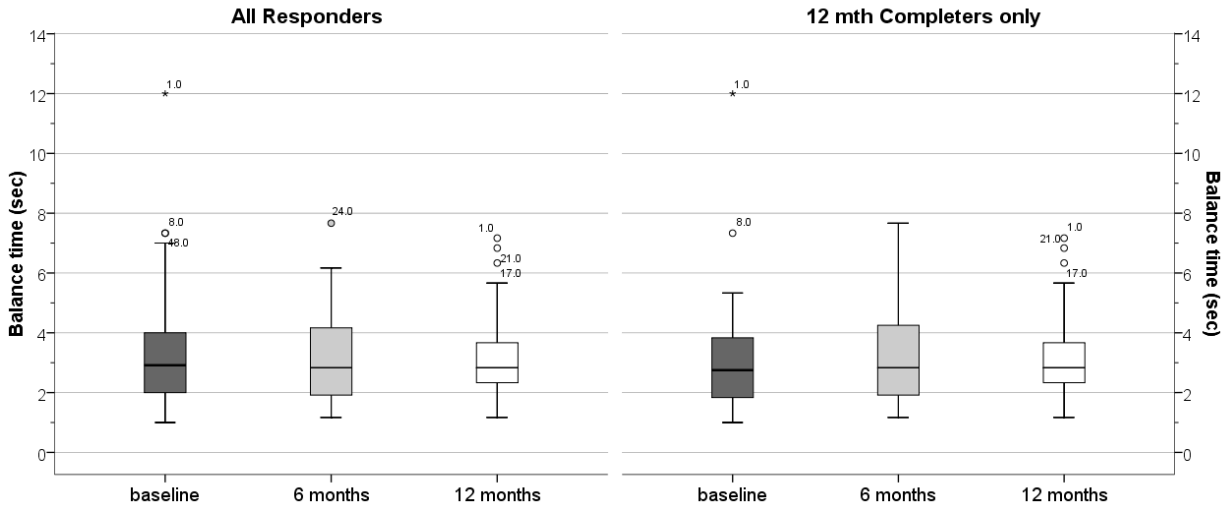
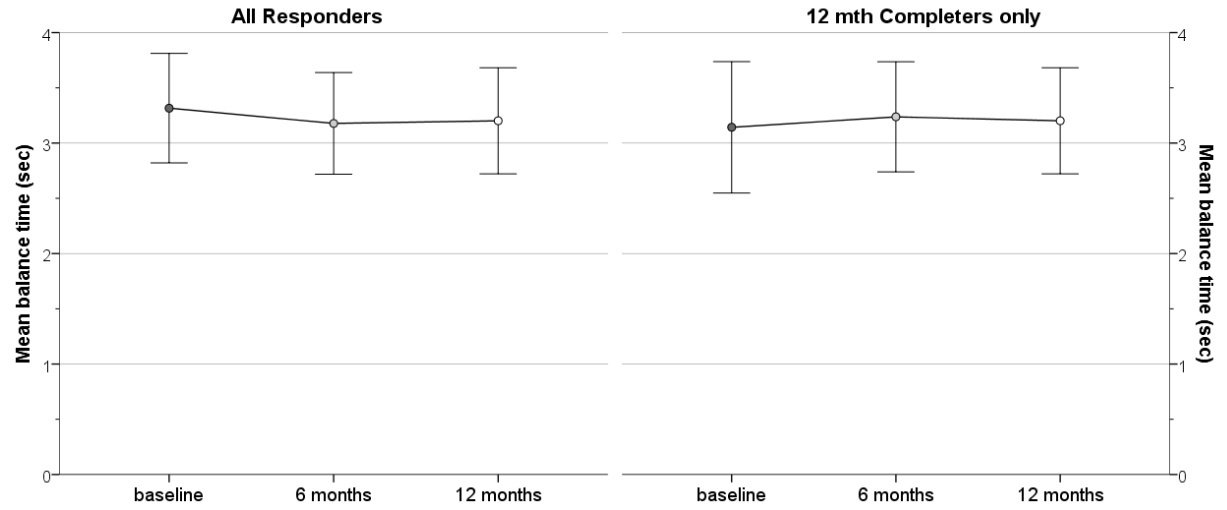


Figure 10.107 Dynamic standing balance - means (95% CI)



10.5 Correlations

Scatter plots were drawn and correlation coefficients calculated to determine potential relationships between spinal deformity and measures of body schema. Cobb angle was used as the measure of spinal deformity. As well as examining relationships with measures of body schema, self-report measures that showed significant relationships with spinal deformity in the cross-sectional correlation study described in chapters 7 and 8 were also analysed. This included the SAQ and KPAQ. Only those plots showing significant correlations are illustrated.

10.5.1 Cobb angle v measures of body schema

Scatterplots that suggested possible relationships between Cobb angle and measures of body schema at 6 and 12 months are presented in

Figure 10.108. Baseline plots are also included to provide context. The plots indicate a linear relationship between Cobb angle and localisation ability suggesting that the number of correct responses decreased with increasing Cobb angle.

Calculation of correlation coefficients revealed a weak negative correlation between Cobb angle and localisation at 6 months which was statistically significant (r=-.388, 95% CI -.631, -.137, p=0.021) (Table 10.45). Cobb angle shared 15.1% of variability with localisation ability (r^2=0.151). A moderate negative correlation was also revealed at 12 months which was on the border of statistical significance (r=-.442, 95% CI -.700, -.044, p=0.051). Correlation coefficients at 6 and 12 months had wide 95% confidence intervals.

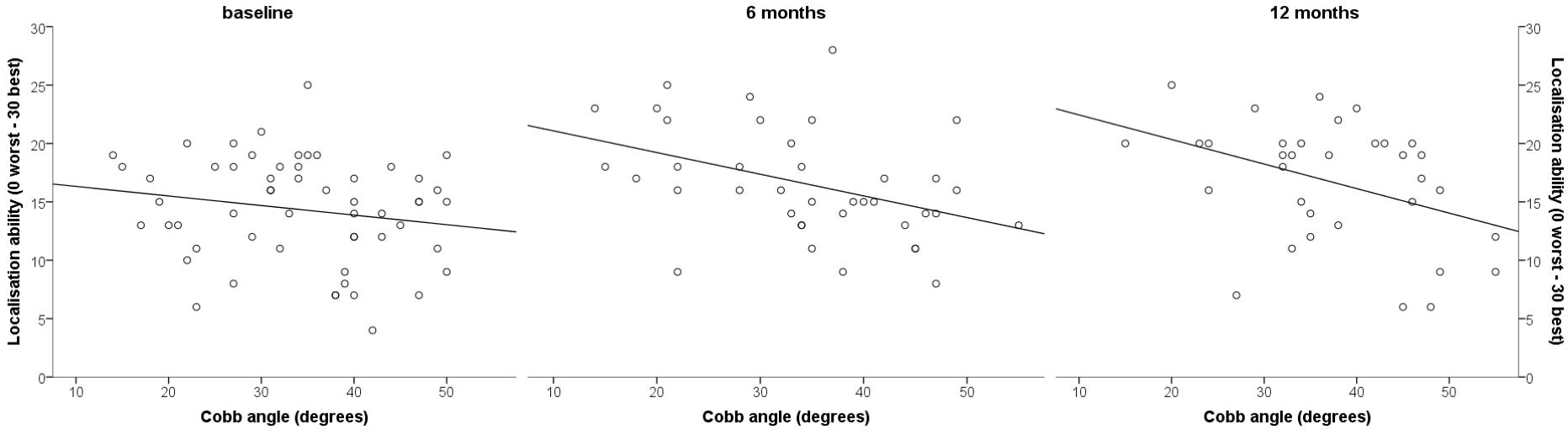
No other observable or statistically significant correlations were noted between Cobb angle and other measures of body schema. Partial correlations revealed no changes in these results when age and disease duration were controlled for. Trial arm and puberty status also failed to exhibit any significant relationship with spinal deformity and measures of body schema with point-biserial correlation testing.

Table 10.45 Correlations - Cobb angle v body schema measures

Cobb angle (°)	TPDT	Localisation	Proprioception	Line Bisection	Laterality				Standing balance
	mm	n correct	absolute error (%)	absolute error (%)	Accuracy Hands (%)	Reaction time Hands (msec)	Accuracy back (%)	Reaction time Back (msec)	seconds
6 month follow up									
Pearson Correlation	.008	**-.388***	-.196	-.150	-.106	-0.288¥	0.175¥	-0.061¥	0.001¥
p-value	.962	.021	.259	.388	.546	.079	.292	.714	.997
BCa 95% Confidence Intervals§	-.265 .277	-.631 -.137	-.487 .075	-.467 .181	-.505 .321	-.581 .035	-.217 .541	-.368 .263	-.325 .341
n	35	35	35	35	35	38	38	38	38
12 month follow up									
Pearson Correlation	-0.132¥	-.442	-0.409¥	-.029	-0.063¥	-0.383¥	0.013¥	0.123¥	-0.303¥
p-value	.580	.051	.073	.905	.793	.096	.957	.606	.193
BCa 95% Confidence Intervals§	-.709 .449	-.700 -.044	-.779 .098	-.359 .298	-.484 .364	-.820 .123	-.388 .398	-.405 .596	-.787 .275
n	20	20	20	20	20	20	20	20	20

* statistically significant; § bootstrap (1000 samples) Bias Corrected accelerated 95% CIs; ¥ Spearman's rho

Figure 10.108 Scatterplots - Cobb angle v Localisation ability



10.5.2 Cobb angle v other measures

Scatterplots of KPAQ and SAQ scales v Cobb angle at 6 and 12 months were reviewed but only the SAQ appearance scale appeared to suggest any relationship (Figure 10.109). A statistically significant weak positive correlation was revealed at 6 months (r=.385, 95% CI .043, .693, p=0.016) and 12 months (r=.364, 95% CI .11, .680, p=.044) (Table 10.46).Cobb angle shared 14.8% and 13.2% of the variability at 6 and 12 months respectively (r^2=0.148 and 0.132). Confidence intervals for the correlation coefficient were again very wide.

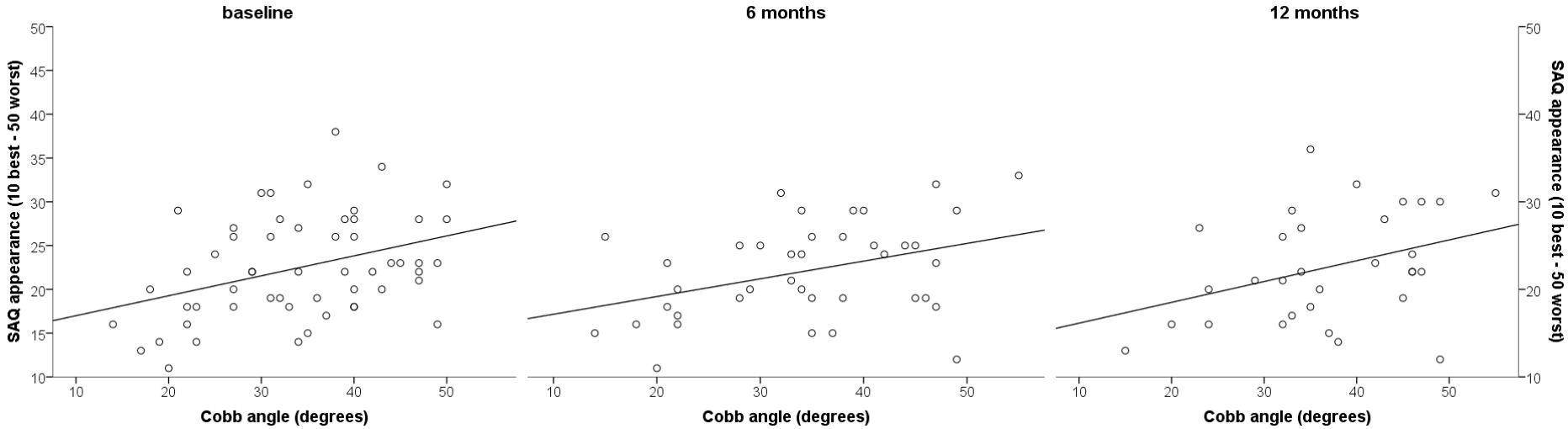
Partial correlations revealed no changes in these results when age and disease duration were controlled for. Trial arm and puberty status also failed to exhibit any significant relationship with spinal deformity and measures of body schema with point-biserial correlation testing.

Table 10.46 Correlations - Cobb v SAQ and KPAQ

	SAQ			KPAQ
Cobb angle (°)	appearance	expectation	total	total
6 months				
Pearson Correlation	**.385***	.032	.248	.130
p-value	.016	.847	.128	.429
BCa 95% Confidence Intervals§	.043 .693	-.285 .355	-.095 .558	-.201 .588
n	39	39	39	39
12 months				
Pearson Correlation	**.364***	.144	.297	.223
p-value	.044	.438	.105	.228
BCa 95% Confidence Intervals§	.011 .680	-.244 .497	-.056 .636	-.090 .503
n	31	31	31	31

* statistically significant; § bootstrap (1000 samples) Bias Corrected accelerated 95% CIs

Figure 10.109 Scatterplots - Cobb angle v SAQ appearance



10.6 Summary

10.6.1 Spinal deformity

On average, there was very little change in the degree of spinal deformity over the study period of 1 year. The Cobb angle decreased by 3-4 degrees on average between baseline and 12 months but this decrease was not statistically significant. It also does not appear to be of any clinical significance falling as it does within the margin of measurement error. Changes of at least 5-10 degrees are normally required before a genuine change in Cobb angle is determined to have taken place [1]. The implications of this when attempting to determine whether changes in spinal deformity are associated with change in other variables are obvious.

10.6.2 Body schema measures

Only two measures of body schema showed any statistically significant change over the 12 month study period. However, it is unclear if these differences are of clinical significance.

TPDT reduced by between 3.5 to 4mm from baseline to 12 month follow-up, the small changes over time reflected in the small effect sizes. Previous studies have reported that changes of at least 13-17mm would be required to provide 95% reliability of a true difference in TPDT in the spine [2, 3].

Left/right judgement accuracy (for both images of the hand and trunk) improved by approximately 5% over time with corresponding reductions in the reaction time of 0.5 to 1 seconds. These were associated with small to moderate effect sizes. There are no previous reports of what constitutes a clinically significant effect for these parameters. Potential issues with test reliability have been documented with contrasting opinions provided by different studies [4, 5]. A learning effect has also been reported in laterality discrimination testing with accuracy improvements of 3% and reductions in reaction time of between 8-20% previously documented [5, 6].

Neither TPDT nor laterality discrimination testing were found to correlate with measures of spinal deformity at either 6 months or 12 months.

10.6.3 Other measures

A number of self-report measures used in this study exhibited statistically significant changes over time. The KPAQ improved by approximately 2-3 points between baseline and 2 months, the small change reflected by the small effect size. Due to the lack of previous studies using this measure, it is difficult to determine if this change represents a meaningful clinical difference in kinaesthetic and proprioceptive awareness. These factors are also known to improve in children as they develop and mature [7].

Changes in the SRS-22r pain scale and the PODCI upper extremity & physical function scale were also observed over time in this study. However, the magnitude of the changes was very small with small effect sizes. The change in the SRS-22r pain scale did not reach previously reported thresholds for minimum detectable change and were close to the reported margins of error [8, 9].

None of these measures were associated with changes in spinal deformity at either the 6 or 12 month follow-up. The SAQ appearance scale did reveal a weak negative correlation indicating that there is some relationship between perception of trunk deformity and changes in spinal deformity.

10.6.4 Limitations

A number of limitations may have affected the results of this study. Firstly, the number of participants who failed to complete testing at all time-points, resulting in missing data, may have compromised the ability of statistical testing to evaluate any changes in the study measures. Descriptive statistics were calculated in an attempt to try and quantify any differences in baseline characteristics between those who completed and those who didn't. Although some differences were evident, these were generally small in nature. However, participants that dropped out of the study tended to be slightly younger and therefore, had the greatest potential for progression of the spinal deformity. Descriptive statistics were also presented to evaluate the difference between participants who completed 12 month follow-up versus all the participants who had data available. In general, the differences between them was small and of doubtful clinical significance.

A further complication related to collecting data for this study from participants who were simultaneously involved in a pilot RCT and therefore undergoing different treatment

interventions. Attempts were made to control for this in the statistical analysis and, in general, trial arm allocation had no effect on the results.

Spinal deformity did not change to any significant degree during the course of this study. This is in accordance with the natural history of AIS as only a small percentage of people with AIS undergo major changes. This means that establishing relationships between changes in spinal deformity and other measures over time is difficult. The lack of changes in measures of body schema observed in this study may simply reflect that the spinal deformity itself did not change, and not necessarily rule out the possibility of their being a relationship. However, the lack of correlation between spinal deformity measures and body schema at all time-points does counter this argument to some extent.

Finally, in common with all observational studies, this study can only evaluate possible associations between variables. It cannot establish the causal nature of any relationship therefore the results of this study should be viewed from this perspective. However, the fact that no significant relationships have been observed suggests that it is unlikely that using other study designs would be likely to result in any differences in results.

10.6.5 Conclusion

The objective of this study was to ascertain whether any relationship exists between changes in mechanisms thought to underpin body schema and progression of the spinal deformity in AIS over time. The results indicate that some measures of body schema did change over the 12 month period in which they were assessed. However, these changes were not matched by any significant corresponding changes in spinal deformity. Correlational analysis also revealed the lack of any relationship between measures of body schema and spinal deformity at both the 6 month and 12 month follow-up, further confirming the lack of apparent association between them. These follow-up results reflect the results of the earlier cross sectional study conducted as part of this thesis and documented in chapter 7.

A relationship between measures of perceived spinal/trunk deformity (SAQ scales) was observed over time, again mirroring the results of the earlier study. This suggests that in people with AIS, perceptions of the level of spinal deformity are associated with the actual magnitude of those changes, at least as measured radiologically by the Cobb angle.

In conclusion, and despite the limitations described previously, the results of this study suggest that there is no relationship between changes in measures thought to underpin body schema and progression of the spinal deformity in people with AIS.

11 Discussion

This thesis set out to determine whether body schema is implicated in the development of adolescent idiopathic scoliosis. It sought to do so by investigating the following research questions:

1. do adolescents with AIS differ from non-scoliotic adolescents with regard to mechanisms that are thought to underpin body schema?
2. in adolescents with AIS, is there any relationship between the mechanisms thought to underpin body schema and the magnitude of spinal deformity?
3. is there any relationship between changes in body schema and progression of the spinal deformity in AIS over time?

11.1 Body schema and adolescent idiopathic scoliosis

For research question 1, a case-control study was conducted to investigate whether there were any differences between people with AIS and non-scoliotic controls with regard to measures of mechanisms underpinning body schema. Of the 9 parameters tested, only 3 resulted in statistically significant differences between groups, all of which were very small with correspondingly small effect sizes, and unlikely to be of meaningful clinical significance.

The potential relationship between the magnitude of spinal deformity in people with AIS (as determined radiographically and by surface topography) and measures of body schema was evaluated for research question 2. A cross-sectional correlational analysis failed to detect any association between spinal deformity and body schema measures. The apparent lack of any relationship was confirmed by the longitudinal analyses conducted to assess changes over time (research question 3). Despite changes in a number of measures of body schema between time-points, there was no corresponding change in measures of spinal deformity. The lack of correlation between spinal deformity and body schema measures at 6 and 12 month follow-ups confirmed the earlier analyses conducted at baseline.

Taken all together, the reviews and analyses conducted as part of this thesis have produced results that do not appear to be consistent with the guidelines of causality as proposed by Bradford-Hill [ref]. There does not appear to be a strong relationship between measures of body schema and AIS (as shown by the systematic review), there is little to no consistency in

results across a multitude of studies examining a variety of neurophysiological measures in AIS (systematic review), and there does not appear to be any specificity or biological gradient between measures of body schema and AIS (from correlational study of body schema versus spinal deformity and longitudinal analyses). In the absence of any information regarding temporality and coherence with other studies, we are left with biological plausibility and analogy (in this case, the results of studies suggesting the role of body schema in certain chronic pain conditions).

Therefore, with regards to the results of the studies and analyses conducted for this thesis, there does not appear currently to be any evidence to associate disruptions in body schema with the development of AIS.

11.2 Other measures and adolescent idiopathic scoliosis

As part of the case-control study, a number of clinically significant between-group differences were observed in other self-report measures such as perceived trunk symmetry and HRQoL, including pain, self-image and function. These differences indicated that on average, people with AIS perceive greater levels of trunk asymmetry and deformity, as well as experiencing greater prevalence and severity of pain, lower self-image and reduced function compared to people without AIS.

11.2.1 Perceived trunk symmetry/deformity

It is perhaps not surprising that people with AIS would perceive their trunk to be substantially different than those without AIS. They have a condition that may involve significant skeletal deformity with associated cosmetic changes to the spine and trunk. The imaging data collected as part of this project confirms that participants had sizeable bony changes, with the majority categorised with moderate AIS. Depending on the time since diagnosis, they may also have been monitored for a considerable period, each review potentially involving some form of imaging or other assessment. Therefore, not only do they have spinal/trunk asymmetries, they are also well aware of the state of their condition and the magnitude of any deformity and subsequent changes. This is highlighted by the results of the correlational analyses conducted at all time-points which showed weak but statistically significant positive relationships between the SAQ and spinal deformity.

11.2.2 Self image

As with perceptions of trunk deformity, it is also not unusual that people with AIS have lower self-image than people without AIS, especially when measured using a condition-specific instrument such as the SRS-22r. It is perhaps compounded by the fact that AIS occurs at an age when children become increasingly body-conscious and more sensitive to differences with peers. The knowledge that the condition may progress could potentially also influence their beliefs with regard to self-image. However, it is interesting to note that ratings of self-image did not appear to be related to measures of spinal deformity as analysed in research questions 2 and 3. In other words, as spinal deformity increased there was not a corresponding decrease in self-image scores, with the two parameters varying independently of each other.

However, a relationship was observed between perceived spinal deformity (as measured by the SAQ) and self-image. Although distinct concepts, it is inevitable that they will be inter-related to some extent in a condition where the major implication is the cosmetic changes that occur as a result of the bony changes in the spine. What is interesting to note is that it is the perceived rather than the actual magnitude of spinal deformity that appears to have the greatest association with the self-image of people with AIS.

Previous studies have reported similar correlations between the SAQ and self-image [1, 2]. However, they also reported similar relationships with actual spinal deformity as measured by the Cobb angle, which was not found in this study. Both of these studies included participants with curves of greater magnitude which may explain the differences between their results and those of this thesis. One of the studies [2] also included participants with other forms of scoliosis.

11.2.3 Pain

Despite the characteristic presence of bony deformity and associated soft-tissue changes, the general clinical consensus is that back pain is not a major feature of AIS and that reports of pain merely reflect the normal prevalence figures for back pain in the wider adolescent population [3]. However, in the case control study conducted as part of this thesis, 2/3 of the participants with AIS reported some pain compared to only 15% of the control participants. Case participants also scored significantly worse on the various pain scales included in the study. These findings are consistent with other reports suggesting that pain, along with

cosmetic changes, is of major concern amongst people with AIS [4, 5]. Despite these observations, the results of the correlational analyses conducted to evaluate research question 2 highlight that pain was not associated with the any of the parameters of spinal deformity. It is possible that the diagnosis of AIS itself and/or cosmetic concerns may be of greater clinical significance with regard to pain.

Evidence for this is provided by the correlational analyses conducted in chapter 8 which highlight the association between two of the three pain measures and perceived spinal deformity as measured by the SAQ. This suggests that the actual physical changes in the spine are not the primary driver of the pain experienced by people with AIS. Rather it is the perception of spinal deformity that appears to be more closely associated with pain in AIS.

11.2.4 Function

Function scores were generally lower for participants with AIS compared to their non-scoliotic counterparts, although between-group differences were smaller than for pain and self-image. This finding is notable as AIS is not generally associated with any significant functional deficits, especially amongst those with mild to moderate scoliosis such as the majority of participants in this study. Again, no association was observed between the magnitude of spinal deformity and any of the function measures. Therefore, self-reported functional ability in people with AIS is lower than people without AIS and this reduction in perceived function is not associated with the actual degree of spinal deformity.

It is interesting to note that the reduction in function scores from self-report measures also does not appear to reflect the various neurophysiological function measures tested as part of the observational study. No major differences in proprioception, balance, spatial awareness or tactile acuity were reported by AIS participants, yet AIS participants considered themselves to be less able to enjoy normal function than control participants, albeit only by a small amount.

Correlational analyses conducted in chapter 8 suggest that the reduced functional ability reported by people with AIS may be related to the perception of spinal deformity. Although the results suggest a much weaker relationship than with self-image and pain, the findings of these analyses indicate that a modest association exists between these domains. These results need to be interpreted with some caution as sizeable ceiling effects were recorded for some of the measures of function used in this thesis. . Similar problems have been previously reported

when using these measures of function in AIS [6]. The binary nature of the mobility and usual activity scales of the EQ5D as used in the analyses conducted as part of this thesis, along with the relatively low numbers of people reporting problems, also means that the observed relationship between function and perceived spinal deformity is less than robust.

11.3 Limitations

A number of limitations have already been discussed in the relevant chapters pertaining to the studies and analyses conducted as part of this research project. The principal limitation is the problem of proving causality when conducting observational studies. However, in the case of this project, no significant associations were observed with regard to the primary hypotheses, although some associations have been detected between perceived spinal deformity and other parameters as part of secondary-analyses. The findings related to these would need to be investigated further using more robust study designs before any definitive judgements can be made as to their veracity.

Another potential limitation is the type of testing that was used to collect data as part of this thesis. This may have resulted in a true relationship between body schema and the development of AIS failing to be detected. Specifically, evaluation using instruments and methods with greater precision may have led to different results. Testing of body schema has previously involved assessment with brain imaging and sophisticated equipment in a laboratory-type environment. However, the practicalities of conducting a case control study within the constraints of a PhD project have meant that these resources were not available, particularly in a multi-site study such as that conducted as part of this thesis. The test regime utilised in this research project was similar to that used previously in other conditions, notably when testing body schema in chronic pain. The results were also, in the main, consistent with those reported from other trials where these techniques were used.

A further limitation was the attrition rate that occurred over the 12 month follow-up period which resulted in missing data. A lower attrition rate would result in greater confidence in the results of the longitudinal analyses and lead to greater precision. Attempts to evaluate the effects of the missing follow-up information were described in chapter 10, and descriptive statistics were calculated to compare the results of those who completed all time-points with those from all responders at each time point. The high attrition rate was largely due to

problems at one recruitment site, and did not appear to be related to people with AIS in general. However, future studies would need to be aware of the potential for high attrition rates and plan accordingly in order to minimise the effect of missing data.

In addition to these, this research project followed people with AIS for 12 months. AIS is a condition that generally develops during the growth spurt associated with puberty and the potential for progression continues until skeletal maturity up to 5-6 years later. In order to capture the entirety of any changes in spinal deformity as well as other parameters, follow-up should continue until physical growth has stopped. The possibility exists that an association between body schema and spinal deformity was not detected due to the short time scale that this study involved. Related to this is the fact that only a small percentage of people with AIS progress to a point where they suffer from significant spinal deformity. As well as not following-up for a longer period, the relatively small numbers of people with AIS recruited as part of this research project may have been insufficient to detect any changes by virtue of there not being enough participants who go on to develop significant spinal deformity. The inclusion of prevalent cases, who may have already undergone all the changes they will ever experience, may also have disguised a true effect of a disrupted body schema on AIS.

Finally, some of the characteristics of the people with AIS that were involved in this research project were not typical of those reported previously in other studies. For example, the study cohort reported, on average, higher prevalence and levels of pain as well as lower self-image than described by other studies. The self-reported ratings for these parameters were more in line with previous studies of people with greater levels of spinal deformity [1, 7-12]. It is possible that the people with AIS included in this research project were experiencing more problems than would be typically expected and that this was a significant factor in their willingness to be involved in this study with a subsequent impact on the results. People with AIS with similar levels of spinal deformity but with less concern or fewer problems may have had less incentive to take part.

11.4 Future directions

There is no evidence from this thesis to support the role of a disrupted body schema in the development of AIS. Therefore, unless new evidence is provided to the contrary, this avenue of investigation does not appear worthwhile pursuing further. Greater emphasis can be focussed

on other more promising factors that may be involved although it is likely that the cause(s) are multi-factorial.

Potentially more important in the short-to-medium term, is to investigate further some of the issues that arose from the secondary analyses. The principal objective in evaluating the possible relationship between body schema and AIS was to design novel methods of therapy as an alternative to the limited, costly and invasive treatments currently available. Although the results of this project indicate that treatment aimed at normalising body schema is not justified, the relationships between perceived spinal deformity and aspects of HRQoL do provide potential avenues of investigation that may lead to the development of alternative methods of dealing with this condition. Altering the AIS patient's perception of their spinal condition may prove to be as fruitful as altering the structure of the spine itself, especially amongst those with mild to moderate scoliosis whose physical condition does not warrant more extreme treatment methods such as surgery, but whose perception of their condition has an impact on other aspects of their life.

11.5 Conclusion

This thesis set out to evaluate the role of body schema in the development of AIS. The results of the studies and analyses conducted as part of this thesis do not provide any evidence to support this hypothesis and therefore suggest that a disrupted body schema is not associated with AIS.

Although not the main focus of this project, differences in perceived spinal deformity and HRQoL were observed in people with AIS compared to non-scoliotic controls. Interestingly, the differences in pain, self-image, and function were not related to the level of actual spinal deformity, suggesting that the physical changes associated with the condition itself were not the important factors. Rather, the knowledge or perception of their condition appeared to be the main drivers of the observed reductions in self-reported function and self-image and the increased prevalence and severity of pain. This has important implications in the management of people with AIS.

Body schema in adolescent idiopathic scoliosis

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Introduction

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Chapter 1

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Chapter 2

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Appendices

Appendix 1 Systematic review search strategies

Medline

1. (AIS adj2 (patient$ or subject$ or girl$ or female$ or boy$ or male$)).ti,ab,kw. 2611

2. (scolio$ adj2 (subject$ or patient$ or child$ or girl$ or group$ or female$ or boy$ or male$ or pediatric$ or paediatric$)).ti,ab,kw. 3688

3. "adolescent idiopathic scoliosis".ti,ab,kw. 3439

4. or/1-3 7688

5. Adolescent/ 1894832

6. (young$ adj1 (adult$ or people$ or person$ or patient$ or girl$ or female$ or male$ or boy$ or child$)).ti,ab,kw. 259978

7. (teenager$ or adolescen$ or juvenile$ or youngster$).ti,ab,kw. 343380

8. or/5-7 2182148

9. Scoliosis/et [Etiology] 2299

10. Scoliosis/pp [physiopathology] 2318

11. (idiopathic adj2 scolios$).ti,ab,kw. 6382

12. 'ISc'.ti,ab,kw. 3735

13. or/9-12 12935

14. 8 and 13 6897

15. exp Neuromuscular Diseases/ 287734

16. ((neuromuscular or neurogenic or neurologic$) adj1 (disease$ or abnormalit$ or disorder$ or difficult$ or deficit$ or dysfunction$ or condition$)).ti,ab,kw. 104465

17. Proprioception/ 7372

18. Kinesthesis/ 3158

19. (propriocepti$ or "position matching" or "movement detection" or kinaesthes$ or kinesthes$ or kinematic$).ti,ab,kw. 42014

20. ((cortical or brain) adj1 (chang$ or reorganisation$ or representation$)).ti,ab,kw. 6274

21. Gait/ 25003

22. Posture/ph [physiology] 16188

23. Postural Balance/ 20646

24. (balanc$ or imbalanc$ or vestibular).ti,ab,kw. 344975

25. ((gait$ or postur$) adj1 (control$ or sway or analys$ or parameter$ or stability or pattern$ or equilibrium or stance or dysfunction or disequilibrium or asymmetr$ or symmetr$)).ti,ab,kw. 19722

26. (lateral$ adj1 discrimination).ti,ab,kw. 25

27. Biomechanical Phenomena/ 104349

28. Biophysical Phenomena/ 15367

29. Evoked Potentials, Somatosensory/ 11930

30. Sensory Thresholds/ 16264

31. Sensation Disorders/pp [physiopathology] 1346

32. Vibration/ 23759

33. (biomechanic$ or biophysical or "tactile acuity" or sensation$ or sensory or percept$ or sensorimotor or somatosensory or localis$ or localiz$ or "temporal order" or vibratory).ti,ab,kw. 1094017

34. (("two point" or sensory) adj1 discrimination).ti,ab,kw. 1717

35. Psychomotor Performance/ 59666

36. Movement/ph [physiology] 25859

37. ((motor or movement$) adj1 (change$ or control$ or function$ or cortex)).ti,ab,kw. 55107

38. ((muscle$ or muscular or rotational) adj2 (change$ or strength$ or activit$ or EMG or function$)).ti,ab,kw. 66926

39. Space Perception/ph [physiology] 15380

40. Visual Perception/ph [physiology] 30550

41. ((spatial or space or visual or orientation) adj1 (perception$ or awareness or process$ or impairment$ or disturbance$)).ti,ab,kw. 30365

42. (subjective adj1 visual adj1 (vertical or horizontal)).ti,ab,kw. 428

43. ((mid-line or midline) adj1 judgement$).ti,ab,kw. 1

44. ('SVV' or 'SSEP').ti,ab,kw. 2020

45. or/15-44 2071221

46. (scolio$ adj4 (physiopatholog$ or neuropatholog$ or neurophysiolog$ or neurogenic$ or neuromuscular or etiopathogenes$)).ti,ab,kw. 598

47. 4 and 45 1862

48. 14 and 45 2046

49. 8 and 46 406

50. 47 or 48 or 49 2875

Embase

1. Adolescent Idiopathic Scoliosis/ 2621

2. (AIS adj2 (patient$ or subject$ or girl$ or female$ or boy$ or male$)).ti,ab,kw. 5180

3. "adolescent idiopathic scoliosis".ti,ab,kw. 4424

4. (scolio$ adj2 (subject$ or patient$ or child$ or girl$ or group$ or female$ or boy$ or male$ or pediatric$ or paediatric$)).ti,ab,kw. 4685

5. or/1-4 11757

6. Idiopathic Scoliosis/ 4165

7. Scoliosis/ 21601

8. (idiopathic adj2 scolios$).ti,ab,kw. 8046

9. 'ISc'.ti,ab,kw. 4390

10. or/6-9 31675

11. Adolescent/ 1385714

12. Adolescence/ 34297

13. (young$ adj1 (adult$ or people$ or person$ or patient$ or girl$ or female$ or male$ or boy$ or child$)).ti,ab,kw. 343470

14. (teenager$ or adolescen$ or juvenile$ or youngster$).ti,ab,kw. 420319

15. or/11-14 1791196

16. 10 and 15 12085

17. exp Neuromuscular Disease/ 173247

18. Neurophysiology/ 26058

19. ((neuromuscular or neurogenic or neurologic$) adj1 (disease$ or abnormalit$ or disorder$ or difficult$ or deficit$ or dysfunction$ or condition$)).ti,ab,kw. 146232

20. Proprioception/ 12337

21. Kinesthesia/ 1917

22. Kinematics/ 21542

23. (propriocepti$ or "position matching" or "movement detection" or kinaesthes$ or kinesthes$ or kinematic$).ti,ab,kw. 49518

24. ((cortical or brain) adj1 (chang$ or reorganisation$ or representation$)).ti,ab,kw. 8783

25. Gait/ 47281

26. Body Position/ 16853

27. Body Equilibrium/ 16405

28. (balanc$ or imbalanc$ or vestibular).ti,ab,kw. 437842

29. ((gait$ or postur$) adj1 (control$ or sway or analys$ or parameter$ or stability or pattern$ or equilibrium or stance or dysfunction or disequilibrium or asymmetr$ or symmetr$)).ti,ab,kw. 27731

30. (lateral$ adj1 discrimination).ti,ab,kw. 29

31. Biomechanics/ 98410

32. Biophysics/ 12968

33. Somatosensory Evoked Potential/ 1510

34. Sensory Evoked Potential/ 317

35. Evoked somatosensory response/ 17184

36. Perceptive Threshold/ 9716

37. Sensory Dysfunction/ 15635

38. Vibration/ 27258

39. Vibration Sense/ 2931

40. Sensory system/ 6437

41. (biomechanic$ or biophysical or "tactile acuity" or sensation$ or sensory or percept$ or sensorimotor or somatosensory or localis$ or localiz$ or "temporal order" or vibratory).ti,ab,kw. 1325436

42. (("two point" or sensory) adj1 discrimination).ti,ab,kw. 1926

43. Psychomotor Performance/ 21483

44. "Movement (physiology)"/ 30696

45. ((motor or movement$) adj1 (change$ or control$ or function$ or cortex)).ti,ab,kw. 77737

46. ((muscle$ or muscular or rotational) adj2 (change$ or strength$ or activit$ or EMG or function$)).ti,ab,kw. 85994

47. Motor dysfunction/ 59680

48. Motor system/ 4724

49. Depth Perception/ 22686

50. Vision/ 71671

51. Visual system function/ 4363

52. Spatial orientation/ 7908

53. Visual system/ 105396

54. Eye hand coordination/ 1762

55. ((spatial or space or visual or orientation) adj1 (perception$ or awareness or process$ or impairment$ or disturbance$)).ti,ab,kw. 40116

56. (subjective adj1 visual adj1 (vertical or horizontal)).ti,ab,kw. 541

57. ('SVV' or 'SSEP').ti,ab,kw. 3138

58. ((mid-line or midline) adj1 judgement$).ti,ab,kw. 1

59. or/17-58 2530745

60. (scolio$ adj4 (physiopatholog$ or neuropatholog$ or neurophysiolog$ or neurogenic$ or neuromuscular or etiopathogenes$)).ti,ab,kw. 843

61. 5 and 59 2769

62. 16 and 59 3440

63. 15 and 60 479

64. 61 or 62 or 63 4627

PsycINFO

1. (AIS adj2 (patient$ or subject$ or girl$ or female$ or boy$ or male$)).ti,ab,id. 176

2. (scolio$ adj2 (subject$ or patient$ or child$ or girl$ or group$ or female$ or boy$ or male$ or pediatric$ or paediatric$)).ti,ab,id. 69

3. "adolescent idiopathic scoliosis".ti,ab,id. 59

4. or/1-3 272

5. Adolescent Development/ 45166

6. "Adolescent".mh. 246082

7. (young$ adj1 (adult$ or people$ or person$ or patient$ or girl$ or female$ or male$ or boy$ or child$)).ti,ab,id. 131923

8. (teenager$ or adolescen$ or juvenile$ or youngster$).ti,ab,id. 262200

9. or/5-8 539901

10. "Scoliosis".mh. 138

11. Spinal Column/ 794

12. Spinal Cord Injuries/ 5108

13. Spinal Cord/ 6492

14. Musculoskeletal Disorders/ 2654

15. (idiopathic adj2 scolios$).ti,ab,id. 95

16. 'ISc'.ti,ab,id. 167

17. or/10-16 14799

18. 9 and 17 1158

19. "Neuromuscular Diseases".mh. 409

20. Neuromuscular Disorders/ 1073

21. Central Nervous System Disorders/ 1758

22. Neurophysiology/ 12652

23. ((neuromuscular or neurogenic or neurologic$) adj1 (disease$ or abnormalit$ or disorder$ or difficult$ or deficit$ or dysfunction$ or condition$)).ti,ab,id. 19847

24. Proprioception/ 930

25. Proprioceptors/ 359

26. "Kinesthesis".mh. 1593

27. (propriocepti$ or "position matching" or "movement detection" or kinaesthes$ or kinesthes$ or kinematic$).ti,ab,id. 10289

28. ((cortical or brain) adj1 (chang$ or reorganisation$ or representation$)).ti,ab,id. 4057

29. Gait/ 2363

30. "gait".mh. 2133

31. "posture".mh. 5927

32. "postural balance".mh. 3768

33. (balanc$ or imbalanc$ or vestibular).ti,ab,id. 74437

34. Equilibrium/ 3289

35. Labyrinth Disorders/ 502

36. ((gait$ or postur$) adj1 (control$ or sway or analys$ or parameter$ or stability or pattern$ or equilibrium or stance or dysfunction or disequilibrium or asymmetr$ or symmetr$)).ti,ab,id. 4333

37. (lateral$ adj1 discrimination).ti,ab,id. 33

38. "Biomechanical Phenomena".mh. 4544

39. "Biophysical Phenomena".mh. 265

40. Somatosensory Disorders/ 1300

41. Somatosensory Evoked Potentials/ 2665

42. "Evoked Potentials, Somatosensory".mh. 2044

43. "Sensory Thresholds".mh. 6474

44. Sensory Deprivation/ 1645

45. "Sensation Disorders".mh. 973

46. Vibration/ 1427

47. Biomechanics/ 408

48. (biomechanic$ or biophysical or "tactile acuity" or sensation$ or sensory or percept$ or sensorimotor or somatosensory or localis$ or localiz$ or "temporal order" or vibratory).ti,ab,id. 473073

49. (("two point" or sensory) adj1 discrimination).ti,ab,id. 567

50. "psychomotor performance".mh. 34550

51. Motor Processes/ 29819

52. Perceptual Motor Processes/ 13315

53. Movement Disorders/ 3138

54. "Movement".mh. 11767

55. ((motor or movement$) adj1 (change$ or control$ or function$ or cortex)).ti,ab,id. 24632

56. ((muscle$ or muscular or rotational) adj2 (change$ or strength$ or activit$ or EMG or function$)).ti,ab,id. 7040

57. "Space Perception".mh. 16958

58. "Spatial Orientation (Perception)"/ 7155

59. Visual Perception/ 39422

60. Vision/ 8867

61. ((spatial or space or visual or orientation) adj1 (perception$ or awareness or process$ or impairment$ or disturbance$)).ti,ab,id. 27475

62. (subjective adj1 visual adj1 (vertical or horizontal)).ti,ab,id. 177

63. ((mid-line or midline) adj1 judgement$).ti,ab,id. 1

64. ('SVV' or 'SSEP').ti,ab,id. 239

65. or/19-64 686839

66. (scolio$ adj4 (physiopatholog$ or neuropatholog$ or neurophysiolog$ or neurogenic$ or neuromuscular or etiopathogenes$)).ti,ab,id. 9

67. 4 and 65 62

68. 18 and 65 363

69. 9 and 66 2

70. 67 or 68 or 69 395

CINAHL

1. ((TI AIS N2 (patient* or subject* or girl* or female* or boy* or male*) OR (AB AIS N2 (patient* or subject* or girl* or female* or boy* or male*)) 1694

2. ((TI scolio* N2 (subject* or patient* or child* or girl* or group* or female* or boy* or male* or pediatric* or paediatric*) OR (AB scolio* N2 (subject* or patient* or child* or girl* or group* or female* or boy* or male* or pediatric* or paediatric*)) 1736

3. ((TI "adolescent idiopathic scoliosis") OR (AB "adolescent idiopathic scoliosis")) 1879

4. (MH "Scoliosis, Idiopathic, Adolescent") 889

5. S1 OR S2 OR S3 OR S4 4495

6. (MH "Adolescence") 438862

7. ((TI young* N1 (adult* or people* or person* or patient* or girl* or female* or male* or boy* or child*) OR (AB young* N1 (adult* or people* or person* or patient* or girl* or female* or male* or boy* or child*)) 87164

8. ((TI teenager* or adolescen* or juvenile* or youngster*) OR (AB teenager* or adolescen* or juvenile* or youngster*)) 468402

9. S6 OR S7 OR S8 520958

10. (MH "Scoliosis/ET") 477

11. (MH "Scoliosis/PP") 635

12. (MH "Scoliosis/DI") 573

13. ((TI idiopathic N2 scolios*) OR (AB idiopathic N2 scolios*)) 2871

14. ((TI "ISc") OR (AB "ISc")) 181

15. S10 OR S11 OR S12 OR S13 OR S14 3954

16. S9 AND S15 2987

17. (MH "Neuromuscular Diseases+") 628885

18. ((TI (neuromuscular or neurogenic or neurologic*) N1 (disease* or abnormalit* or disorder* or difficult* or deficit* or dysfunction* or condition*) OR (AB (neuromuscular or

neurogenic or neurologic*) N1 (disease* or abnormalit* or disorder* or difficult* or deficit* or dysfunction* or condition*)) 16948

19. (MH "Proprioception") 2839

20. (MH "Kinesthesis") 594

21. (MH "Kinetics") 5225

22. (MH "Kinematics") 13058

23. ((TI propriocepti* or "position matching" or "movement detection" or kinaesthes* or kinesthes* or kinematic*) OR (AB propriocepti* or "position matching" or "movement detection" or kinaesthes* or kinesthes* or kinematic*)) 20081

24. ((TI (cortical or brain) N1 (chang* or reorganisation* or representation*) OR (AB (cortical or brain) N1 (chang* or reorganisation* or representation*)) 2747

25. (MH "Gait") 8815

26. (MH "Posture/PH") 2583

27. (MH "Balance, Postural") 13615

28. ((TI balanc* or imbalanc* or vestibular) OR (AB balanc* or imbalanc* or vestibular)) 65888

29. (TI (gait* or postur*) N1 (control* or sway or analys* or parameter* or stability or pattern* or equilibrium or stance or dysfunction or disequilibrium or asymmetr* or symmetr*) OR (AB (gait* or postur*) N1 (control* or sway or analys* or parameter* or stability or pattern* or equilibrium or stance or dysfunction or disequilibrium or asymmetr* or symmetr*)) 9508

30. ((TI lateral* N1 discrimination) OR (AB lateral* N1 discrimination)) 5

31. (MH "Biomechanics") 19689

32. (MH "Biophysics") 1122

33. (MH "Evoked Potentials, Somatosensory") 1333

34. (MH "Evoked Potentials/PH") 1624

35. (MH "Sensation Disorders/PP") 307

36. (MH "Vibration") 3429

37. ((TI biomechanic* or biophysical or "tactile acuity" or sensation* or sensory or percept* or sensorimotor or somatosensory or localis* or localiz* or "temporal order" or vibratory) OR (AB biomechanic* or biophysical or "tactile acuity" or sensation* or sensory or percept* or sensorimotor or somatosensory or localis* or localiz* or "temporal order" or vibratory)) 210946

38. ((TI ("two point" or sensory) N1 discrimination) OR (AB ("two point" or sensory) N1 discrimination)) 270

39. (MH "Psychomotor Performance") 10565

40. (MH "Movement/PH") 3285

41. ((TI (motor or movement*) N1 (change* or control* or function* or cortex) OR (AB (motor or movement*) N1 (change* or control* or function* or cortex)) 13005

42. ((TI (muscle* or muscular or rotational) N2 (change* or strength* or activit* or EMG or function*) OR (AB (muscle* or muscular or rotational) N2 (change* or strength* or activit* or EMG or function*)) 22341

43. (MH "Spatial Perception") 2485

44. (MH "Visual Perception") 10217

45. ((TI (spatial or space or visual or orientation) N1 (perception* or awareness or process* or impairment* or disturbance*) OR (AB (spatial or space or visual or orientation) N1 (perception* or awareness or process* or impairment* or disturbance*)) 6807

46. ((TI (subjective N1 visual N1 (vertical or horizontal) OR (AB (subjective N1 visual N1 (vertical or horizontal)) 116

47. ((TI (mid-line or midline) N1 judgement*) OR (AB (mid-line or midline) N1 judgement*)) 1

48. (TI ('SVV' or 'SSEP') OR (AB ('SVV' or 'SSEP')) 420

49. S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27 OR S28 OR S29 OR S30 OR S31 OR S32 OR S33 OR S34 OR S35 OR S36 OR S37 OR S38 OR S39 OR S40 OR S41 OR S42 OR S43 OR S44 OR S45 OR S46 OR S47 OR S48 411398

50. ((TI (scolio* N4 (physiopatholog* or neuropatholog* or neurophysiolog* or neurogenic* or neuromuscular or etiopathogenes*) OR (AB (scolio* N4 (physiopatholog* or neuropatholog* or neurophysiolog* or neurogenic* or neuromuscular or etiopathogenes*)) 256

51. S5 and S49 990

52. S16 and S49 785

53. S9 and S50 167

54. S51 OR S52 OR S53 1247

SportDISCUS

1. (DE "Adolescent idiopathic scoliosis") 77

2. ((TI AIS N2 (patient* or subject* or girl* or female* or boy* or male*) OR (AB AIS N2 (patient* or subject* or girl* or female* or boy* or male*) OR (KW AIS N2 (patient* or subject* or girl* or female* or boy* or male*)) 130

3. ((TI scolio* N2 (subject* or patient* or child* or girl* or group* or female* or boy* or male* or pediatric* or paediatric*) OR (AB scolio* N2 (subject* or patient* or child* or girl* or group* or female* or boy* or male* or pediatric* or paediatric*) OR (KW scolio* N2 (subject* or patient* or child* or girl* or group* or female* or boy* or male* or pediatric* or paediatric*)) 291

4. ((TI "adolescent idiopathic scoliosis") OR (AB "adolescent idiopathic scoliosis") OR (KW "adolescent idiopathic scoliosis")) 213

5. S1 OR S2 OR S3 OR S4 548

6. (DE "Teenagers") 28669

7. ((TI young* N1 (adult* or people* or person* or patient* or girl* or female* or male* or boy* or child*) OR (AB young* N1 (adult* or people* or person* or patient* or girl* or female*

or male* or boy* or child*) OR (KW young* N1 (adult* or people* or person* or patient* or girl* or female* or male* or boy* or child*)) 20738

8. ((TI teenager* or adolescen* or juvenile* or youngster*) OR (AB teenager* or adolescen* or juvenile* or youngster*) OR (KW teenager* or adolescen* or juvenile* or youngster*)) 38705

9. S6 OR S7 OR S8 75731

10. (DE "Scoliosis") 638

11. (DE "Scoliosis treatment") 107

12. (KW "scoliosis") 262

13. ((TI idiopathic N2 scolios*) OR (AB idiopathic N2 scolios*) OR (KW idiopathic N2 scolios*)) 370

14. ((TI "ISc") OR (AB "ISc") OR (KW "ISc")) 118

15. S10 OR S11 OR S12 OR S13 OR S14 998

16. S9 AND S15 371

17. (DE "Neuromuscular Diseases") 695

18. ((TI (neuromuscular or neurogenic or neurologic*) N1 (disease* or abnormalit* or disorder* or difficult* or deficit* or dysfunction* or condition*) OR (AB (neuromuscular or neurogenic or neurologic*) N1 (disease* or abnormalit* or disorder* or difficult* or deficit* or dysfunction* or condition*) OR (KW (neuromuscular or neurogenic or neurologic*) N1 (disease* or abnormalit* or disorder* or difficult* or deficit* or dysfunction* or condition*)) 2441

19. (DE "Proprioception") 1981

20. (DE "Muscular sense") 580

21. (DE "Dynamics") 3219

22. (DE "Kinematics") 9572

23. (DE "Human kinematics") 982

24. ((TI propriocepti* or "position matching" or "movement detection" or kinaesthes* or kinesthes* or kinematic*) OR (AB propriocepti* or "position matching" or "movement detection" or kinaesthes* or kinesthes* or kinematic*) OR (KW propriocepti* or "position matching" or "movement detection" or kinaesthes* or kinesthes* or kinematic*)) 19054

25. ((TI (cortical or brain) N1 (chang* or reorganisation* or representation*) OR (AB (cortical or brain) N1 (chang* or reorganisation* or representation*) OR (KW (cortical or brain) N1 (chang* or reorganisation* or representation*)) 490

26. (DE "Gait in humans") 5088

27. (DE "Gait disorders") 1692

28. (DE "Posture") 8309

29. (DE "Equilibrium (Physiology)") 3960

30. ((TI balanc* or imbalanc* or vestibular) OR (AB balanc* or imbalanc* or vestibular) OR (KW balanc* or imbalanc* or vestibular)) 31621

31. (TI (gait* or postur*) N1 (control* or sway or analys* or parameter* or stability or pattern* or equilibrium or stance or dysfunction or disequilibrium or asymmetr* or symmetr*) OR (AB (gait* or postur*) N1 (control* or sway or analys* or parameter* or stability or pattern* or equilibrium or stance or dysfunction or disequilibrium or asymmetr* or symmetr*) OR (KW (gait* or postur*) N1 (control* or sway or analys* or parameter* or stability or pattern* or equilibrium or stance or dysfunction or disequilibrium or asymmetr* or symmetr*)) 8246

32. ((TI lateral* N1 discrimination) OR (AB lateral* N1 discrimination) OR (KW lateral* N1 discrimination)) 6

33. (DE "Biomechanics") 29837

34. (DE "Biophysics") 1151

35. ((TI biomechanic* or biophysical or "tactile acuity" or sensation* or sensory or percept* or sensorimotor or somatosensory or localis* or localiz* or "temporal order" or vibratory) OR (AB biomechanic* or biophysical or "tactile acuity" or sensation* or sensory or percept* or sensorimotor or somatosensory or localis* or localiz* or "temporal order" or vibratory) OR (KW biomechanic* or biophysical or "tactile acuity" or sensation* or sensory or percept* or sensorimotor or somatosensory or localis* or localiz* or "temporal order" or vibratory)) 82430

36. ((TI ("two point" or sensory) N1 discrimination) OR (AB ("two point" or sensory) N1 discrimination) OR (KW ("two point" or sensory) N1 discrimination)) 92

37. (DE "Psychology of movement") 1418

38. (DE "Movement disorders") 1370

39. (DE "Perceptual-motor processes") 4737

40. ((TI (motor or movement*) N1 (change* or control* or function* or cortex) OR (AB (motor or movement*) N1 (change* or control* or function* or cortex) OR (KW (motor or movement*) N1 (change* or control* or function* or cortex)) 7435

41. ((TI (muscle* or muscular or rotational) N2 (change* or strength* or activit* or EMG or function*) OR (AB (muscle* or muscular or rotational) N2 (change* or strength* or activit* or EMG or function*) OR (KW (muscle* or muscular or rotational) N2 (change* or strength* or activit* or EMG or function*)) 22332

42. (DE "Spatial behavior") 237

43. (DE "Visual Perception") 2185

44. (DE "Motion perception (Vision)") 97

45. (DE "Sensorimotor cortex") 124

46. ((TI (spatial or space or visual or orientation) N1 (perception* or awareness or process* or impairment* or disturbance*) OR (AB (spatial or space or visual or orientation) N1 (perception* or awareness or process* or impairment* or disturbance*) OR (KW (spatial or space or visual or orientation) N1 (perception* or awareness or process* or impairment* or disturbance*)) 2185

47. ((TI (subjective N1 visual N1 (vertical or horizontal) OR (AB (subjective N1 visual N1 (vertical or horizontal) OR (KW (subjective N1 visual N1 (vertical or horizontal)) 22

48. ((TI (mid-line or midline) N1 judgement*) OR (AB (mid-line or midline) N1 judgement*) OR (KW (mid-line or midline) N1 judgement*)) 0

49. (TI ('SVV' or 'SSEP') OR (AB ('SVV' or 'SSEP') OR (KW ('SVV' or 'SSEP')) 44

50. (DE "Visual evoked response") 181

51. (DE "Evoked potentials (Electrophysiology)") 1758

52. S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27 OR S28 OR S29 OR S30 OR S31 OR S32 OR S33 OR S34 OR S35 OR S36 OR S37 OR S38 OR S39 OR S40 OR S41 OR S42 OR S43 OR S44 OR S45 OR S46 OR S47 OR S48 OR S49 OR S50 OR S51 174233

53. ((TI (scolio* N4 (physiopatholog* or neuropatholog* or neurophysiolog* or neurogenic* or neuromuscular or etiopathogenes*) OR (AB (scolio* N4 (physiopatholog* or neuropatholog* or neurophysiolog* or neurogenic* or neuromuscular or etiopathogenes*) OR (KW (scolio* N4 (physiopatholog* or neuropatholog* or neurophysiolog* or neurogenic* or neuromuscular or etiopathogenes*)) 28

54. S5 and S52 187

55. S16 and S52 126

56. S9 and S53 12

57. S54 OR S55 OR S56 220

PEDro

1. In Abstract & Title:'scoliosis'

CDAS

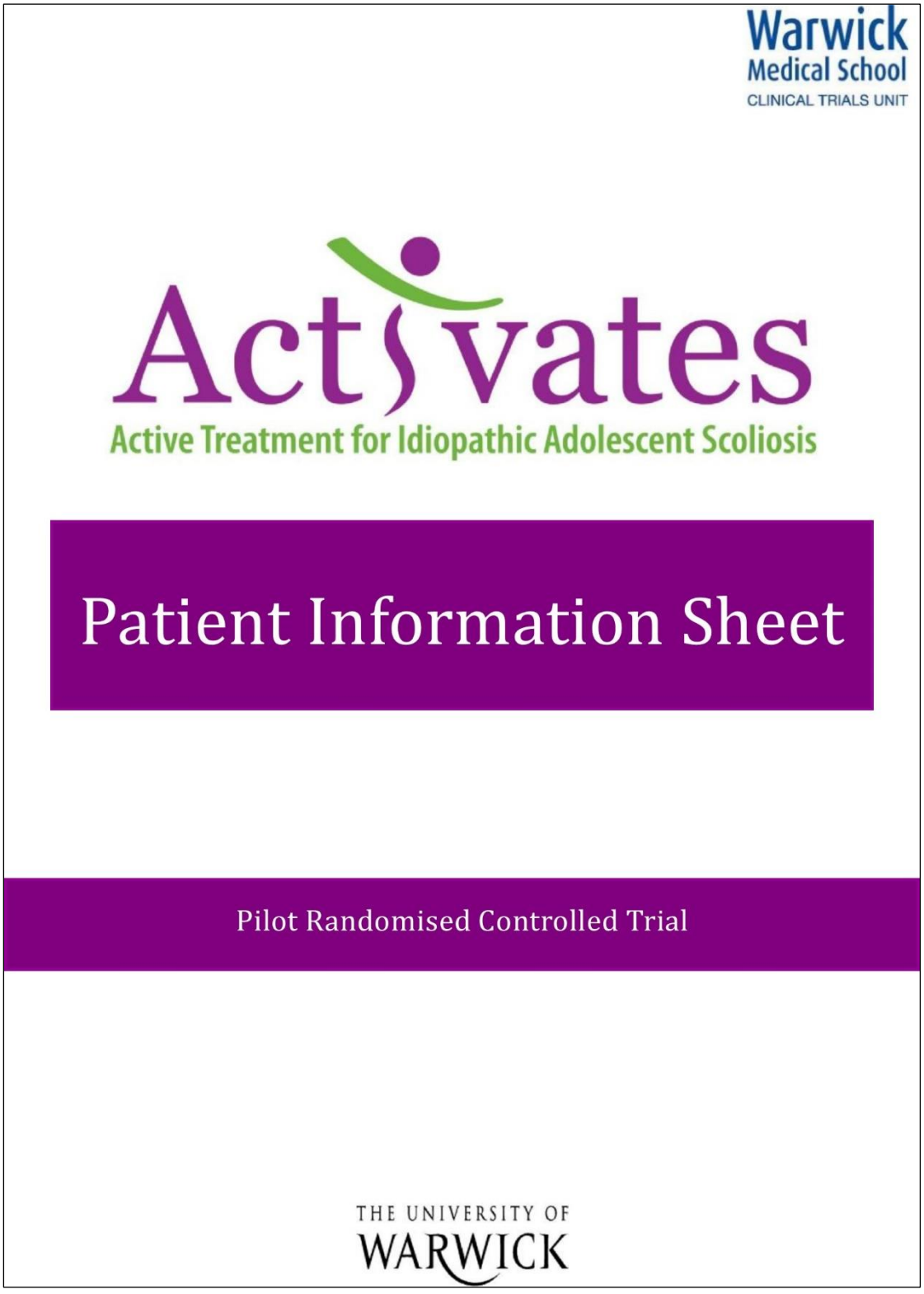
1. (ZU "Scoliosis") 16

2. ((TI "scoliosis") OR (AB "scoliosis")) 67

3. S1 OR S2 67

Appendix 2 Participant information sheets (cases)

A2.1 Older child participant information sheet (cases)



Study of two treatments programmes for Adolescent Idiopathic Scoliosis (AIS)

You have been invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what you would have to do. Please take the time to read the following information carefully and to explain and discuss it with your parents and with others if you wish. Please ask any questions you might have and we will try to answer any queries. Take your time to decide whether or not you wish to take part. Thank you for reading this.

What is the purpose of the study?

The research we are asking you to take part in is a pilot study. This means that we are running a small study to collect information to see whether it is possible to run a much larger clinical trial investigating two different physiotherapy treatments for Adolescent Idiopathic Scoliosis (AIS). The treatments that we are testing in this pilot study are the treatments that we would like to test in a larger study.

At present, there are very few treatments for AIS used routinely in the NHS apart from surgery and sometimes bracing. We want to find out if other treatments are also helpful. In particular, we want to test out if providing extra support and exercises helps patients with scoliosis.

At the moment we do not know which of these would be the most helpful treatment for young people with AIS. Extra support and exercises are not usually provided for young people with AIS by the NHS. This pilot study will test out how easy it is to find young people to take part in the study and what the young people and their parents think of the treatments as well as get some idea if these treatments are helpful.

Why have I been invited to take part?

You have been invited because you have AIS and you are between 10-16 years old.

Do I have to take part?

It is up to you to decide whether or not to take part. If you decide to take part, you are free to withdraw at any time and without giving a reason. The decision will not affect your care in any way. If you do decide to take part, you will be asked to sign a form to say that you agree to take part.

What will taking part involve?

First, you will come to a hospital appointment with a researcher who will be a physiotherapist or nurse. The appointment will last approximately 60 to 90 minutes. At the appointment we will ask you some questions about your scoliosis and how it affects you. Then we will take some measurements including height, weight, body awareness and a special video scan of your back. This type of scan is not like an x-ray or MRI - you will stand as you usually do and a special video will take pictures to see the position of your back. We will also ask you if you will let us look at your hospital records for information about your condition (including any x-rays you have had in the past).

Next, we will tell you which of the treatments you are going to have. This is decided by a computer. The computer randomly chooses which treatment programme you would receive, similar to tossing a coin. In this trial you have an equal chance (50:50) of having either of the two treatments. The reason we need to do this is that we do not know the best way to treat patients with AIS and we need to compare the different treatments that are available. This is called a randomised controlled trial. The decision is made by the computer and cannot be changed; so you have to be

happy to accept either treatment. At this stage, we do not know which treatment is better for treating AIS.

All patients will receive a full assessment with a physiotherapist who has specialist training in the management of scoliosis. This physiotherapist will advise you on how best to manage your scoliosis and give general advice about physical activity and support groups and, where necessary, advice on brace use and care. This will involve up to 2 sessions, each one lasting a maximum of 60 minutes.

In addition, some patients will have the option of additional sessions with the physiotherapist who will provide specific exercises for scoliosis and supervise your progress with these exercises. This will involve up to 8 extra sessions each lasting 30-40 minutes and exercises at home.

Some patients will be asked to keep a record of the exercises completed on an internet diary, and to join an internet support group on a secure web-site with other children with scoliosis in this study.

Six months and again at 12 months after your first appointment, you will be asked to come to a follow-up appointment where the questions and measurements that were done during the first appointment will be repeated. This is so that we can see if there have been any changes. All appointments will be at the same hospital as your normal hospital appointments. You will continue to be looked after by your consultant as usual. If the study is successful and we are given permission to conduct a bigger study, we may also ask similar questions and take some measurements once every year until you don't have to see the consultant anymore for your scoliosis. We will try and ensure that this is at the same time as your normal consultant review appointments.

You and your parents may also be asked if you would like to be interviewed about being in the study after you have taken part. You will be given information about the interview during the treatment sessions and can make a separate decision about whether you want to be interviewed after the treatment is finished

Expenses and Payments

We will pay for the costs of you and your parents coming to the research appointments so that your parents will not have extra expense. You need to provide travel receipts so please make sure you collect these. We are unable to routinely pay for any expenses incurred to attend for the study treatments.

What are the possible benefits/disadvantages to taking part?

We hope that taking part in the study will help you. However, this cannot be guaranteed. Specialist advice from a physiotherapist may help you to understand AIS and how to deal with it better. The information we get from this study may help us to run a bigger trial in the future which we hope will help to improve treatment for patients with AIS.

We do not expect any problems from you taking part. Occasionally people feel

uncomfortable for a short time after beginning an exercise programme. This is normal and not usually long lasting. You will be able to carry on with your usual day to day activities and sports.

Would my participation in this study be kept confidential?
All information collected will be kept private. Information taken from the medical notes will have your name removed and the information collected will not be kept with your personal details. The questionnaire will not ask for names or personal details. You will not be able to be identified when the research results are written up into a report.

Researchers have a legal responsibility to make sure that young people involved in research are kept safe so the only time we would pass on information about you to someone outside the study is if we were concerned for your safety.

What happens at the end of the study?
After you have finished the treatment as part of the study, your consultant will continue to see you as usual. If permission is given to conduct a larger study, we may ask you to redo the measures and questions once every year until you are discharged by your consultant. We will try to make sure this happens at the same time you come in for your consultant appointment.

What if new information becomes available?
Sometimes, during the course of a research study, new information becomes available about the treatment that is being studied. If this happens, the hospital or researchers will tell you about it and discuss with you and your parents whether you want to continue in the study. If you decide to withdraw from the research they will make arrangements for your care to continue. It is possible the hospital or researchers might consider it to be in your best interests for you to stop taking part in the study. They will explain the reasons and arrange for your care to continue.

What will happen if I don't want to carry on with the study?
You can stop taking part in the study at any point and it will not affect any treatment you receive at your hospital or with your GP.

What will happen to the results of the research study?
The data collected will be analysed and the results will be used to write a research report and articles for doctors and other health professionals. In any report or publication we will not use your real name, and will not give any details that could identify you. We will post a regular report of the trial progress on our web-site: www.warwick.ac.uk/go/activatesstudy

Who is organising and funding the research?
The person responsible for the research is Professor Sallie Lamb from the University of Warwick. It is being paid for by the National Health Service's Health Technology Assessment Programme.

Who is being paid for this research?
The researchers involved in this study will not be paid for including you in the study. No one taking part will receive a payment for inclusion either.

Who has reviewed this Study?
This study was reviewed by independent experts involved in the awarding of the funding for the study. Independent scientists and doctors working on behalf of the NHS Health Technology Assessment Agency reviewed this study and agreed that it was an important clinical question to investigate. The study has received a favourable ethical opinion by NRES Committee East of England – Cambridge South.

What if I have any concerns?
If you have any concerns about this study or the way it is being carried out, you or your parents should contact:

Dr Mark Williams
ACTIVATES Study Lead
Warwick Clinical Trials Unit
University of Warwick
Gibbet Hill Campus
Coventry CV4 7AL
Tel: [redacted] Fax: [redacted]

E-Mail: activates@warwick.ac.uk

Or you may contact the Patient Advice and Liaison Service (PALS) at your hospital:

PALS Office
Insert hospital name
Insert address
Telephone: insert
Email: insert

What do we do next?
A member of the research team at the University of Warwick will phone your parents to discuss your participation in this research further. If you have decided you may want to take part in the study then we will arrange a time for you to attend the hospital for a research clinic assessment. During this appointment you will talk about the study with the researcher and ask any questions you may have. If you definitely want take part in the study you will then be asked to sign a form to say that you are happy to take part. Your parent will also be asked to sign this form to say they also agree for you to take part in the study.

If you are going to take part, please bring a pair of shorts to clinic appointments as these will be more comfortable for you when you have the measurements taken. During the video-scan, we will need to see your back without any covering in order to see your spine properly.

Contact for further information:
If you have any questions or you would like any more information then please contact the research physiotherapist at your hospital:

Name: *Insert research clinician name here*

Telephone: *Insert research clinician's phone number here* Email: *Insert research clinician's email here*

If we are not able to take your call, please leave a message and we will call you back.

Thank you for taking the time to read this information and for considering whether or not to take part.

A2.2 Younger child participant information sheet (cases)

Warwick Medical School
CLINICAL TRIALS UNIT

Actívates

Active Treatment for Idiopathic Adolescent Scoliosis

Patient Information Sheet

THE UNIVERSITY OF WARWICK

Younger child Version 2.0 24.9.2012
ISRCTN90480705

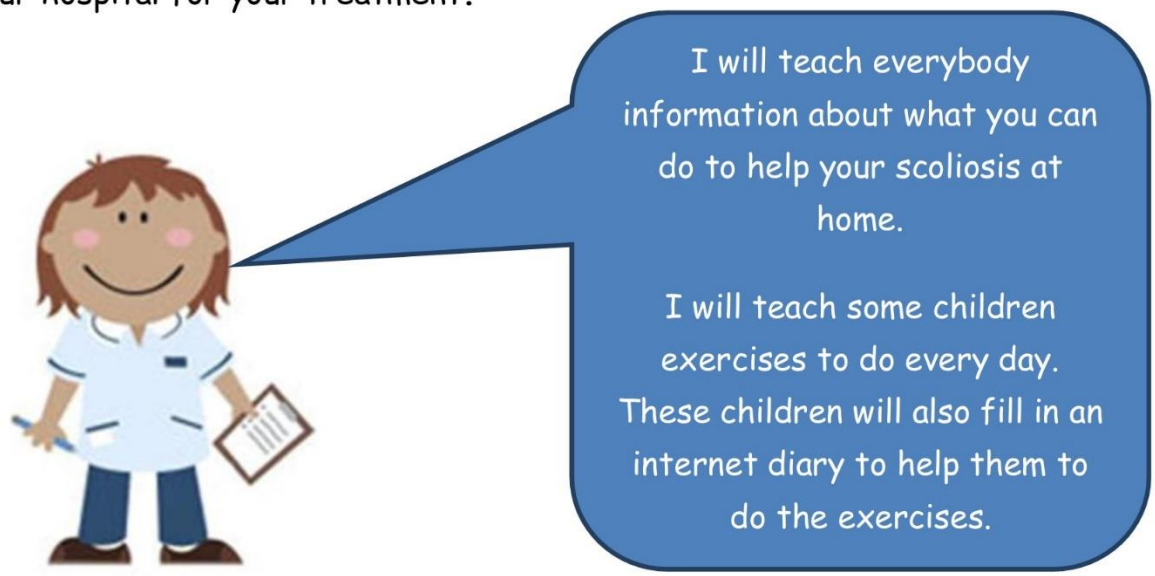
You have been invited to take part in a study. To help you to decide whether you want to take part, read our information sheet.

What is a study?

This is just like the sort of experiment you would do in maths or science lessons except that we do all the maths and science and tell you what we find later. We want to find out which is the best treatment for children with scoliosis so we are going to compare two treatments.

What are the two treatments?

We are testing two physiotherapy treatments. Physiotherapists are people who work with children and their families to help them get better from illness, injury or other conditions such as scoliosis. You will visit a physiotherapist at your hospital for your treatment.



PHYSIOTHERAPIST

Why have you invited me?
Because you have scoliosis and you are between 10-16 years old.

Do I have to do it?
No! We are inviting you to join us. You decide if you want to do it.

What will happen if I say no?
We will thank you for reading this information sheet and you will carry on having your normal treatment for your scoliosis.

What will happen if I say yes?
You and your parents will need to come to a hospital appointment with a physiotherapist or nurse. They will ask you some questions and take some measurements.

Treatment is allocated by chance. This means that our computer will decide which treatment you will have.

This is called randomisation.

It is just like flipping a coin to decide which of the two treatments you will receive.

In six months time when you have had your treatment and then again in 12 months, we will ask you back to your hospital for another appointment with the physiotherapist or nurse. This is so they can see if the treatment has helped. They will ask you some questions and take some measurements just like the first appointment. If the study is successful, we may also ask similar questions and take some measurements once every year until you don't have to see the consultant anymore for your scoliosis.

Am I the only one taking part?

No! We are looking for 50 children to take part in the study.

Why should I take part?

The treatment may help you but we also hope this research will help provide better treatment for other children with scoliosis in the future.

What happens now?

Have a talk with your parents and decide if you would like to do the study.

Thank you for reading this information and for thinking about taking part in our study.

A2.3 Parent participant information sheet (cases)

Warwick Medical School
CLINICAL TRIALS UNIT

Activates
Active Treatment for Idiopathic Adolescent Scoliosis

Patient Information Sheet

Information for parents

Pilot Randomised Controlled Trial

THE UNIVERSITY OF WARWICK

Study of two treatments programmes for Adolescent Idiopathic Scoliosis (AIS)

Your child has been invited to take part in a research study. Before you decide whether you are happy for child to take part in the study, it is important for you to understand why the research is being done and what it involves. Please take the time to read the following information carefully and to explain and discuss it with your child and with others if you wish. Please ask any questions you or your child might have and we will try to answer any queries. Take your time to make your decision. Thank you for reading this.

What is the purpose of the study?

The research we are asking your child to take part in is a pilot study. This means that we are running a small study to collect information to see whether it is possible to run a much larger clinical trial investigating two different physiotherapy treatments for Adolescent Idiopathic Scoliosis (AIS). The treatments that we are testing in this pilot study are the treatments that we would like to test in a larger study.

At present, there are very few treatments for AIS used routinely in the NHS apart from surgery and sometimes bracing. We want to find out if other treatments are also helpful. In particular, we want to test out if providing extra support and exercises helps patients with scoliosis.

At the moment we do not know which of these would be the most helpful treatment for young people with AIS. Extra support and exercises are not usually provided for young people with AIS by the NHS. This pilot study will test out how easy it is to find young people to take part in the study and what the young people and their parents think of the treatments as well as to get some idea if these treatments are helpful.

Why has your child been invited to take part?

Your child has been invited because they have AIS and are between 10-16 years old.

Who decides if my child should take part?

Both you and your child need to agree for them to take part in the study. This is referred to as providing consent to take part in research and involves signing a consent form. You or your child can sign the consent form depending on how well your child is able to understand the information provided. Your child has been provided with their own information sheet that is appropriate for their level of understanding. If your child is younger and you feel they may not fully understand about the research then we will ask you to sign the consent form for them. You as their parent are trusted to make this decision with their best interests in mind. However, the child still needs to agree to take part. If you are happy that your child can make this decision for themselves then your child can sign the consent form. However, you still need to be happy that this is the right decision.

Does my child have to take part?

It is up to you and your child to decide whether or not you want your child to take part. If you decide to take part, you are free to withdraw your child at any time and without giving a reason. The decision will not affect your family's healthcare in any way.

What will taking part involve?

Initially you and your child will have to come to a hospital appointment with a researcher who will be a physiotherapist or nurse. The appointment will last approximately 60 to 90 minutes. First of all you and your child will need to complete a questionnaire which asks questions about your child's scoliosis and how it affects them. Then we will take some measurements including height, weight, body awareness and a special video scan of your child's back. This type of scan is not like an x-ray or MRI – your child will stand normally and a special video will take pictures of the back to see the alignment of the spine. We will also ask for your consent to access information about your child's condition (including x-rays) from their medical notes.

Your child would then be allocated to one of the two treatment programmes and the effects of these treatments will be compared. The reason we need to do this is that we do not know the best way to treat patients with AIS and we need to compare the different treatments that are available. A computer is used to decide randomly which treatment programme your child would receive, similar to tossing a coin. In this trial they have an equal chance (50:50) of receiving either of the two treatments. This is called a randomised controlled trial. The decision is made by the computer and cannot be changed; therefore you both have to be prepared to accept either option. At this stage, we do not know which option is better for treating AIS.

All patients will receive a full assessment with a physiotherapist who has specialist training in the management of scoliosis. This physiotherapist will advise you on how best to manage your scoliosis and give general advice about physical activity and support groups and, where necessary, advice on brace use and care. This will involve up to 2 sessions, each one lasting a maximum of 60 minutes.

In addition, some patients will have the option of additional sessions with the physiotherapist who will provide specific exercises for scoliosis and supervise your progress with these exercises. This will involve up to 8 extra sessions each lasting 30-40 minutes and exercises at home. Some patients will be asked to keep a record of the exercises completed on an internet diary, and to join an internet support group on a secure web-site with other children with scoliosis in this study.

Six months and again at 12 months after the initial assessment appointment, you and your child will be asked to come to a follow-up appointment where the questionnaires and measurements will be repeated so that we can see if there have been any changes. All treatments and assessments will occur at the same hospital as your child's consultant appointments. Your child will continue to be looked after by their consultant as usual. If the study is successful and we are given permission to conduct a bigger study, we may also ask similar questions and take some measurements once every year until your child is discharged from consultant care. We will try and ensure that this is at the same time as the normal consultant review appointments. You and your child may also be asked to be interviewed about being in the study after your child has attended for their treatment. You will be given information about the interview during the treatment sessions and can make a separate decision about whether you and your child want to be interviewed after the treatment is finished.

Expenses and Payments
So that you will not be out of pocket by participating in this research, we will pay for your transport costs (taxi / public transport) to attend for the research assessments. Transport costs will be reimbursed only if you provide travel receipts so please make sure you collect these. We are unable to routinely pay for any expenses incurred to attend for the study treatments.

What are the possible benefits/disadvantages to taking part?
We hope that participation in the study will help your child. However, this cannot be guaranteed. Specialist advice will be provided by a physiotherapist which may help them to understand AIS and how to deal with it better. The information we get from this study may help us to run a bigger trial in the future which we hope will help to improve treatment for patients with AIS.

We do not anticipate any problems from your child's participation. Apart from the time required to take part in the study, we do not anticipate any inconvenience would be caused to you or your child. Occasionally people experience short-term discomfort after beginning an exercise programme. This is a normal response to treatment and is not usually long lasting. All children who take part can continue with their normal activities and sports.

Would my child's participation in this study be kept confidential?
All information collected will be kept in the strictest confidence. Information taken from the medical notes will have your child's name removed and the information collected will not be kept with your personal details. The questionnaire will not ask for names or personal details. Your child will not be able to be identified when the research results are written up into a report. Researchers have a legal responsibility to make sure that children involved in research are kept safe so the only time we would pass on information about your child to someone outside the study is if we were concerned for their safety. . With your agreement we will inform your child's GP that they are taking part in the study.

What happens at the end of the study?
After completing their allocated treatment as part of the trial, the consultant will continue to see your child as usual. If this initial pilot study is given permission to continue into a bigger study, we may ask your child to complete further re-assessments once every year until they are discharged, preferably when they come in for their normal consultant appointment.

What if relevant new information becomes available?
Sometimes, during the course of a research study, new information becomes available about the treatment that is being studied. If this happens, the hospital or researchers will tell you about it and discuss with you whether your child should continue in the study. If you decide to withdraw from the research they will make arrangements for your care to continue. Also, on receiving new information the hospital or researchers might consider it to be in best interests of your child to withdraw from the study. They will explain the reasons and arrange for your child's care to continue.

What will happen if either my child or I don't want to carry on with the study?
Your child may stop taking part in the study at any point and it will not affect any treatment your family receive at your hospital or with your GP.

What will happen to the results of the research study?

The data collected will be analysed and the results will be used to write a research report and journal articles for doctors and other health professionals. In any report or publication we will not use your child's real name, and will not give any details that could identify them. We will post a regular report of the trial progress on our web-site: www.warwick.ac.uk/go/activatesstudy

Who is organising and funding the research?

The person responsible for the research is Professor Sallie Lamb from the University of

Warwick. It is being paid for by the National Health Service's Health Technology Assessment Programme.

Who is being paid for this research?

The researchers involved in this study will not be paid for including you in the study. No participants will receive a payment for inclusion either.

Who has reviewed this study?

This study was reviewed by independent experts involved in the awarding of the funding for the study. Independent scientists and doctors working on behalf of the NHS Health

Technology Assessment Agency reviewed this study and agreed that it was an important clinical question to investigate. The study has received a favourable ethical opinion by NRES Committee East of England – Cambridge South.

What if I have any concerns?

If you have any concerns about this study or the way it is being carried out, you should contact:

Dr Mark Williams
ACTIVATES Study Lead
Warwick Clinical Trials Unit
University of Warwick
Gibbet Hill Campus
Coventry CV4 7AL
Tel: [redacted]
Fax:
E-Mail: activates@warwick.ac.uk

Or you may contact the Patient Advice and Liaison Service (PALS) at your hospital:

PALS Office
Insert hospital name
Insert address
Telephone: insert
Email: insert

What do we do next?

A member of the research team at the University of Warwick will phone you to discuss your child's participation in this research further. If you and your child have decided they may

want to take part in the study then we will arrange a time for you both to attend the hospital for a research clinic assessment. During this appointment you will talk about the study with the researcher and ask any questions you may have. If you both definitely want take part in the study you will then be asked to sign a form to say that you are happy to take part as discussed earlier.
If you think your child is going to take part, please bring a pair of shorts to clinic appointments to improve their comfort during the study. During the video-scan, we will need to see their back without any covering in order to see their spine properly.

Contact for further information:
If you have any questions or you would like any more information then please contact the research physiotherapist/nurse at your hospital:

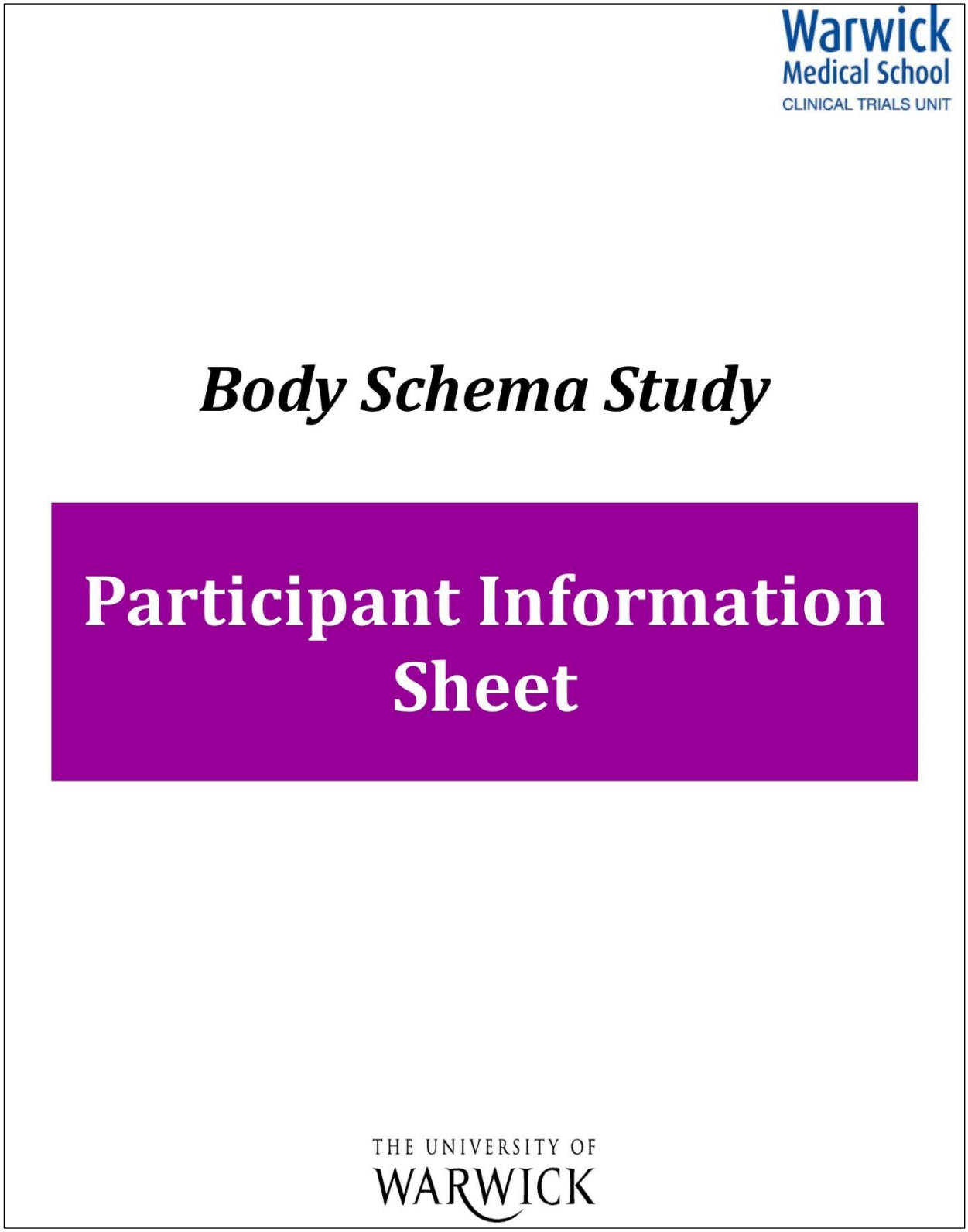
Name: *Insert research clinician name here*
Telephone: *Insert research clinician's phone number here*
Email: *Insert research clinician's email here*

If we are not able to take your call, please leave a message and we will call you back.

Thank you for taking the time to read this information and for considering whether or not to take part.

Appendix 3 Participant information sheets (controls)

A3.1 Older child participant information sheet (controls)



You have been invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what you would have to do. Please take the time to read the following information carefully and to explain and discuss it with your parents and with others if you wish. Please ask any questions you might have and we will try to answer any queries. Take your time to decide whether or not you wish to take part. Thank you for reading this.

What is the purpose of the study?

The research we are asking you to take part in forms part of a larger study. We have already collected information and performed physical tests of young people with scoliosis (a curvature of the spine). What we would now like to do is to collect similar information and perform similar tests on young people without scoliosis to try and find factors that are associated with this condition and maybe possible causes.

The reason we are asking you to participate is because we believe you do not have scoliosis and would make a good comparison with someone who does have scoliosis. By looking at the differences between people such as you and those with scoliosis, we can highlight the different factors that are linked to this condition.

Why have I been invited to take part?

Your school has given permission to approach you to take part in this study. Where possible, the session will take place at your school. You have been invited because you are between 10-16 years old and do not suffer from scoliosis or any other associated conditions.

Do I have to take part?

It is up to you to decide whether or not to take part. If you decide to take part, you are free to withdraw at any time and without giving a reason.

What will taking part involve?

First of all you will need to complete a questionnaire which asks general questions about your health etc. Then you will be seen by a researcher who is a physiotherapist or nurse who will take some measurements including height, weight, and balance. The appointment will last approximately 30 – 40 minutes.

Some of the testing will be on your back and will involve tapping various parts of the spine to see how good your sense of 'touch' is. Other tests will involve determining how well you can tell your left from your right. You will be able to wear normal clothing although you may find it more comfortable to wear shorts.

This will be a one-off session and you will not have to come back for further visits. The testing will be performed at your school.

Expenses and Payments

We do not anticipate that involvement in the study will involve any cost to you or your parents.

What are the possible benefits/disadvantages to taking part?

We do not anticipate any problems from your participation. Apart from the time required to take part in the study, we do not anticipate any inconvenience would be caused to you.

Occasionally people may notice some red marks on their skin as a result of light pressure but these should not last more than 15 – 30 minutes. This is a normal response to some of the tests. None of the tests should cause you any pain. Everyone who takes part can continue with their normal activities and sports.

As part of the testing process, you will have a clinical assessment of your back including a test to see if you have scoliosis. If anything of significance is found, we will report back to your parents and give advice regarding further assessment through the NHS.

Would my participation in this study be kept confidential?
All information collected will be kept private. Information taken will have your name removed and the information collected will not be kept with your personal details. The questionnaire will not ask for names or personal details. You will not be able to be identified when the research results are written up into a report.

Researchers have a legal responsibility to make sure that young people involved in research are kept safe so the only time we would pass on information about you to someone outside the study is if we were concerned for your safety.

What happens at the end of the study?
Once the session is over, your involvement in the study will have ended. There will be no need for the research team to make any further contact with you or your parents.

What will happen if I don't want to carry on with the study?
You can stop taking part in the study at any point and it will not affect anything with your school or teachers.

What will happen to the results of the research study?
The data collected will be analysed and the results will be used to write a research report and articles for doctors and other health professionals. In any report or publication we will not use your real name, and will not give any details that could identify you. If you wish to receive further information regarding the results of this study, you can contact the research team using the details below.

Who is organising and funding the research?
The person responsible for the research is Mr Peter Heine from the University of Warwick. It is being paid for by the National Health Service's Doctoral Research Fellowship programme.

Who is being paid for this research?
The researchers involved in this study will not be paid for including you in the study. No one taking part will receive a payment either.

Who has reviewed this Study?
This study was reviewed by independent experts involved in the awarding of the funding for the study. Independent scientists and doctors working on behalf of the NHS Doctoral Research Fellowship programme reviewed this study and agreed that it was an important clinical question to investigate. The study has received a favourable ethical opinion from the University of Warwick Medical Ethics committee. Your school has also agreed to us asking if you would like to be involved.

What if I have any concerns?
If you have any concerns about this study or the way it is being carried out, you should contact:

Jo Horsburgh
Deputy Registrar
Deputy Registrar's Office
University of Warwick
Coventry CV4 8UW
Tel: [redacted]
E-Mail: [redacted]

What do we do next?
A consent form is included in the pack. If you are happy to be involved, please complete the form along with your parents and return it in the envelope provided or return it to the school reception. Both you and your parents need to complete and sign the form. We will then arrange a time and place for the testing session with your school.

If you do not want to take part, please complete the form by ticking the box to say you are not interested. If we don't hear from you, the researcher may contact you again to ask if you would like to take part.

If you or your parents would like to discuss the study further, you can use the contact details above.

If you think you are going to take part, please make sure you bring a pair of shorts to the appointment to improve your comfort during the session.

Contact for further information:
If you have any questions or you would like any more information, then please contact Mr Peter Heine on [redacted] or by email [redacted]. If we are not able to take your call, please leave a message and we will call you back.

Thank you for taking the time to read this information and

for considering whether or not to take part.

A3.2 Younger child participant information sheet (controls)

Warwick Medical School
CLINICAL TRIALS UNIT

Body Schema Study

Participant Information Sheet

THE UNIVERSITY OF WARWICK

You are invited to take part in a study. Your school has given permission to ask if you would like to take part. To help you to decide whether you want to, please read our information sheet.

What is a study?

This is just like the sort of testing you would do in maths or science lessons except that we do all the maths and science and tell you what we find later.

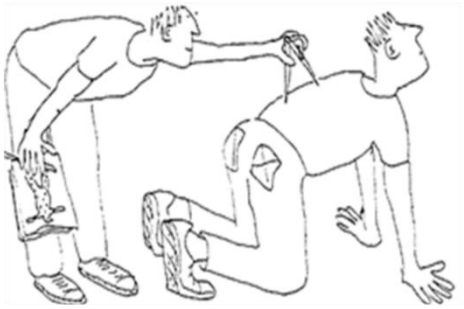
In this study, we have already tested a group of children just like you except they have a condition called scoliosis, which means their spine is bent rather than straight like yours. We want to find out if there is any difference between them and children without scoliosis like you in different tests.

What are the tests?

We will ask you a bunch of questions and then test things like how good you are at telling your left from you right.

We will also test your balance and measure your height and weight.

Other tests include how well you can tell where someone is tapping you on your back and if they are tapping your back with one point or two.



The tests should take 30 minutes or so and will be done by a Researcher. Their job is to explain to you about the tests and then to do them with you. They can answer any questions that you have. They will come to your school to do the testing.

RESEARCHER

I will ask you and your parents if you are interested in being in the study.

The tests shouldn't cause you any pain. They are quick, simple and hopefully fun!

Why have you invited me?

Because you are between 10-16 years old and do not have scoliosis or any other medical or health problems.

Do I have to do it?

No! We are inviting you to join us. You decide if you want to do it.

What will happen if I say no?

Nothing. We thank you for reading this information sheet and you can carry on with your normal life.

What will happen if I say yes?

The researcher will come to see you at school. They will ask you some questions and take some measurements like those already described.

They will choose a time that is best for you and your teachers.

Am I the only one taking part?

No! We are looking for between 50 to 200 children to take part in the study.

Why should I take part?

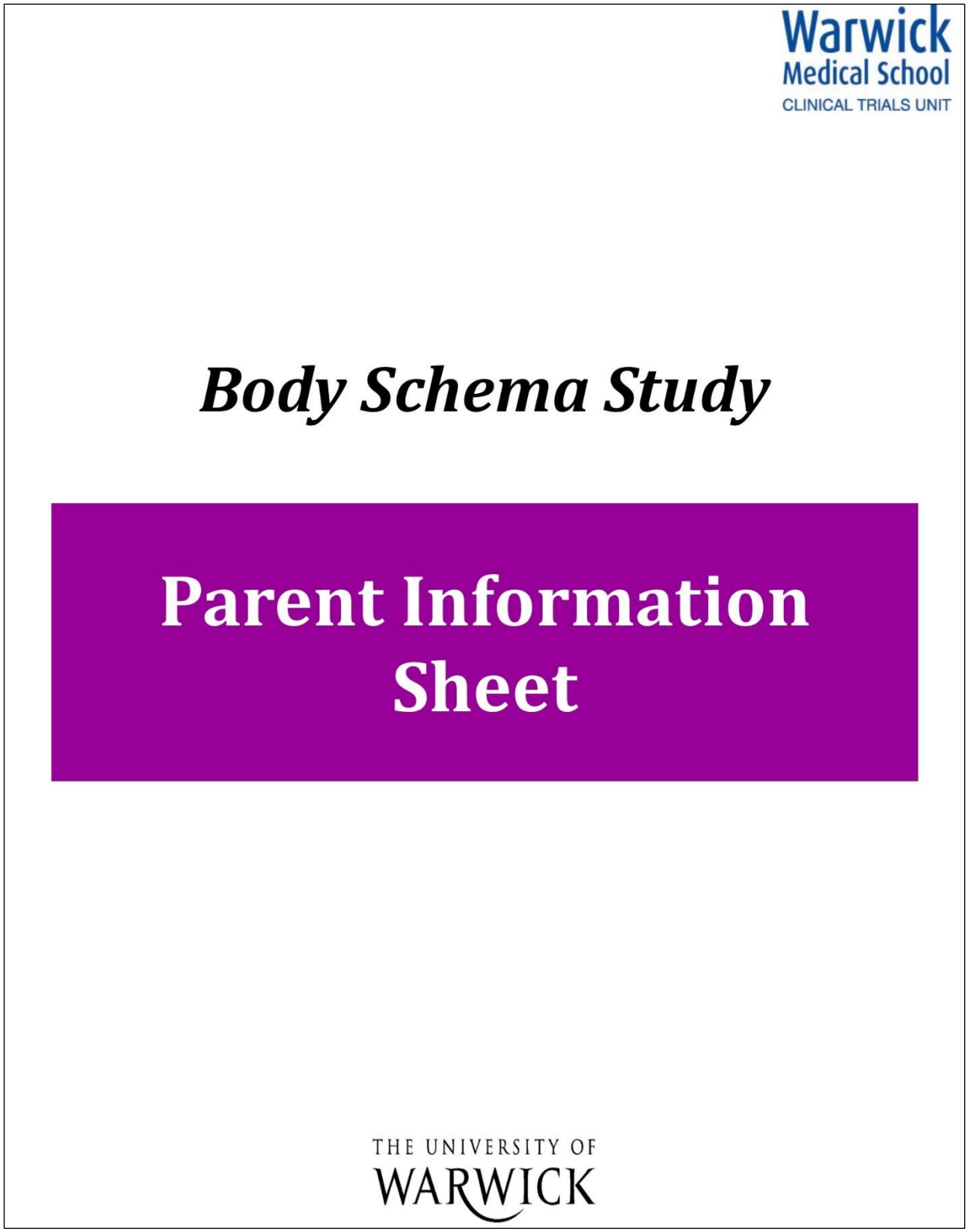
We hope this research will help provide better treatment for children with scoliosis in the future.

What happens now?

Have a talk with your parents and decide if you would like to do the study. Then complete the form to say if you want to be involved or not and return it.

Thank you for reading this information and for thinking about taking part in our study.

A3.3 Parent participant information sheet (controls)



Your child has been invited to take part in a research study. Before you decide whether you are happy for your child to take part in the study, it is important for you to understand why the research is being done and what it involves. Please take the time to read the following information carefully and to explain and discuss it with your child and with others if you wish. Please ask any questions you or your child might have and we will try to answer any queries. Take your time to make your decision. Thank you for reading this.

What is the purpose of the study?
The research we are asking your child to take part in forms part of a larger study. We have already collected information and performed physical tests of young people with scoliosis (a curvature of the spine). What we would now like to do is to collect similar information and perform similar tests on young people without scoliosis to try and find factors that are associated with this condition and possible causes. The reason we are asking your child to participate is because we believe they do not have scoliosis and would make a good comparison with someone who does have scoliosis. By looking at the differences between children such as yours and those with scoliosis, we can highlight the different factors that are linked to this condition.

Why has your child been invited to take part?
Your school has given permission to approach you to take part in this study. Your child has been invited because they are between 10-16 years old and do not suffer from scoliosis or any other associated conditions.

Who decides if my child should take part?
Both you and your child need to agree for them to take part in the study. This is referred to as providing consent to take part in research and involves signing a consent form. You and your child both need to sign the consent form. Your child has been provided with their own information sheet. If your child is younger and you feel they may not fully understand about the research, then you as their parent are trusted to make this decision with their best interests in mind. However, your child still needs to agree to take part.

Does my child have to take part?
It is up to you and your child to decide whether or not you want your child to take part. If you decide to take part, you are free to withdraw your child at any time and without giving a reason.

What will taking part involve?
First of all they will need to complete a questionnaire which asks general questions about your child's health etc. Your child will then be seen by a researcher who is a physiotherapist or nurse who will take some measurements including height, weight, and balance. The appointment will last approximately 30 – 40 minutes.

Some of the testing will be on the child's back and will involve tapping various parts of the spine to see how good their sense of 'touch' is. Other tests will involve determining how well they can tell their left from their right. Your child will be able to wear their normal clothing although they may find it more comfortable to wear shorts. For some of the tests, we will need to see their back without any covering in order to view their spine properly. A responsible adult (e.g. school nurse, teacher or if you wish, yourself) will be present throughout the session alongside the researcher. All researchers involved have appropriate DBS clearance to work with children.

This will be a one-off session and your child will not have to come back for further visits. The testing will be performed at your child's school or, if you prefer, at a location convenient to you both.

Expenses and Payments
We do not anticipate that involvement in the study will involve any cost to you or your child.

What are the possible benefits/disadvantages to taking part?
We do not anticipate any problems from your child's participation. Apart from the time required to take part in the study, we do not anticipate any inconvenience would be caused to you or your child. Occasionally people may notice some red marks on their skin as a result of light pressure but these should not last more than 15 – 30 minutes. This is a normal response to some of the tests. None of the tests should cause any pain. All children who take part can continue with their normal activities and sports.

As part of the testing process, your child will have a clinical assessment of their back including a test to see if they have scoliosis. If anything of significance is found, we will report back to you and give advice regarding further assessment through the NHS.

Would my child's participation in this study be kept confidential?
All information collected will be kept in the strictest confidence. Information taken will have your child's name removed and the information collected will not be kept with their personal details. The questionnaire will not ask for names or personal details. Your child will not be able to be identified when the research results are written up into a report. Researchers have a legal responsibility to make sure that children involved in research are kept safe so the only time we would pass on information about your child to someone outside the study is if we were concerned for their safety. All staff involved have received an enhanced Criminal Records Bureau check and training in the safe guarding of children.

What happens at the end of the study?
Once the session is over, your child's involvement in the study will have ended. There will be no need for the research team to make any further contact with you or your child.

What will happen to the results of the research study?
The data collected will be analysed and the results will be used to write a research report and journal articles for doctors and other health professionals. In any report or publication we will not use your child's real name, and will not give any details that could identify them. If you wish to receive further information regarding the results of this study, you can contact the research team using the details below.

Who is organising and funding the research?
The person responsible for the research is Mr Peter Heine from the University of Warwick. It is being paid for by the National Health Service's Doctoral Research Fellowship programme.

Who is being paid for this research?
The researchers involved in this study will not be paid for including you in the study. No participants will receive a payment either.

Who has reviewed this study?
This study was reviewed by independent experts involved in the awarding of the funding for the study. Independent scientists and doctors working on behalf of the NHS Doctoral Research Fellowship programme reviewed this study and agreed that it was an important clinical question to investigate. The study has received a favourable ethical opinion from the University of Warwick Medical Ethics committee. Your child's school has also given permission for us to approach you.

What if I have any concerns?
If you have any concerns about this study or the way it is being carried out, you should contact:

Jo Horsburgh, Deputy Registrar, Deputy Registrar's Office
University of Warwick, Coventry CV4 8UW,
Tel: [redacted] E-Mail: [redacted]

What do we do next?
A consent form is included in the pack. If you are happy to be involved, please complete the form along with your child and return it in the envelope provided or return it to the school reception. Both you and your child need to complete and sign the form. We will then arrange a time and place for the testing session with the school.

If you do not want to take part, please complete the form by ticking the box to say you are not interested. If we don't hear from you, the researcher may contact you again to ask if you would like to take part.

If you or your child would like to discuss the study further, you can use the contact details above.

If you think your child is going to take part, please make sure they bring a pair of shorts to the appointment to improve their comfort during the session.

Contact for further information:
If you have any questions or you would like any more information then please contact Mr Peter Heine on [redacted] or email [redacted]

If we are not able to take your call, please leave a message and we will call you back.

Thank you for taking the time to read this information and for considering whether or not to take part.

Appendix 4 Consent & eligibility forms

A4.1 Child consent form (cases)

Local NHS Trust logo Inserted here

Act vates
Active Treatment for Idiopathic Adolescent Scoliosis

Warwick Medical School
CLINICAL TRIALS UNIT

ACTIvATeS: ACtive Treatment for Idiopathic Adolescent Scoliosis
PARTICIPANT CONSENT FORM

1.	I confirm that I have read the patient information sheet dated **24.9.2012, Version 3.0**, for the above study. I have been able to think about the information, ask questions and have had these answered in a way that makes sense to me.	Please initial here
2.	I understand that I do not have to take part and that I am free to leave the study at any time without giving reasons and without any effect on my medical care or legal rights.	Please initial here
3.	I agree to a member of the study team being able to see my health care records as described in the information sheet.	Please initial here
4.	I agree to my GP being told about my participation in the study.	Please initial here
5.	I know that the research team will keep my address and telephone number and contact me and my parents again in 6 and 12 months' time to collect further information. If this small study becomes a bigger study, I understand that I may be asked to repeat this once a year until I am discharged by my consultant.	Please initial here
6.	I agree to take part in the above study.	Please initial here
7.	I agree to being contacted by one of the study team to talk about being interviewed for the study.	Please initial here

NAME OF PARTICIPANT	Date (dd/mm/yyyy)	Participant's signature
_____	_____	_____
PERSON TAKING CONSENT	Date (dd/mm/yyyy)	Signature of person taking consent
_____	_____	_____

I (NAME) _____ am the parent (carer) of the above patient.
I have had the opportunity to read the patient information sheet, consider the information and ask questions.
I agree with name of child's declaration of consent and agree to their participation in the study.

A4.2 Parent consent form (cases)

Local NHS Trust logo Inserted here

Activates
Active Treatment for Idiopathic Adolescent Scoliosis

Warwick Medical School
CLINICAL TRIALS UNIT

ACTIvATeS: ACtive Treatment for Idiopathic Adolescent Scoliosis
PARENTAL CONSENT FORM

1.	I confirm that I have read the patient information sheet dated **24.9.2012, Version 3.0** for the above study. I have had the opportunity to consider the information, ask questions and have had these answered in a way that makes sense to me.	Please initial here
2.	I understand that in giving consent for name of participant to take part in the study I am acting in his/her best interests.	Please initial here
3.	I understand that his/her participation is voluntary and that I am free to withdraw my consent at any time without giving reasons and without any effect on name of participant's medical care or legal rights.	Please initial here
4.	I agree to a member of the study team accessing his/her (delete as appropriate) health care records as described in the information sheet.	Please initial here
5.	I agree to name of participant's GP being informed of their participation in the study.	Please initial here
6.	I am aware that the research team will hold my contact details and contact me again in 6 and 12 months' time to collect follow up information. If this initial pilot study becomes a bigger study, I understand that my child may be asked to repeat this once a year until they are discharged by the consultant.	Please initial here
7.	I agree to name of participant taking part in the above study.	Please initial here
8.	I agree to being contacted by one of the study team to talk about myself and name of participant being interviewed.	Please initial here

NAME OF PARENT (CARER) Date (dd/mm/yyyy) Parent's signature

_____ _____ _____

PERSON TAKING CONSENT Date (dd/mm/yyyy) Signature of person taking consent

_____ _____ _____

I (PARTICIPANT'S NAME) _____ have been able to read the participant information sheet for the study and have had it explained to me by name of researcher who has answered my questions in a way that makes sense to me.
I agree to take part in the ACTIvATeS study.

Participant's signature _____ Date_____

A4.3 Eligibility checklist (cases)

ACTIvATeS Research Clinic

Eligibility Checklist Form

Recruitment Centre: | Research clinic date: / / Day Month Year

Initials: | Date of birth: / / Day Month Year

Study number (if applicable):

Attendance at research clinic: Attended ☐ DNA ☐ Cancelled appointment ☐

Rebooked research clinic

Research clinic date: / / Day Month Year

Attendance at research clinic: Attended ☐ DNA ☐ Cancelled appointment ☐

Eligibility check list (Please place a cross in the box):

The answer must be "yes" to all the following questions to be eligible for the trial:

Eligibility Criteria	***Yes***	***No***
Aged between 10 and 16 years of age		
Has been diagnosed with mild to moderate Adolescent Idiopathic Scoliosis defined by a Cobb angle between 10-50 degrees		

The answer must be "no" to all the following questions to be eligible for the trial:

Eligibility Criteria	***Yes***	***No***
Has had previous surgery		
Is on a waiting list for spinal surgery within the next 6 months.		
Has a diagnosis of non-idiopathic scoliosis, for example congenital malformations, syringomyelia, neurofibromatosis, spina bifida, polio and cerebral palsy.		

1. **Is this young person eligible for enrolment in the trial based on the eligibility criteria?**

Yes ☐ **No** ☐

Reason for ineligibility:

2. **Is the young person willing to participate in the trial?**

Yes ☐ **No** ☐

If "no", please ask the young person to identify reason:
(The patient does not need to give a reason but this is useful information for us)

☐ I do not want to receive one or both of the interventions:

Please circle which: Advice session Exercise programme Both

☐ I do not have the time to take part in the study

☐ I am not happy about being part of a research project.

☐ Other – please state:

---

3. **Is the parent willing for their child to participate in the trial?**

Yes ☐ **No** ☐

If "no", please ask the parent to identify reason:
(The patient does not need to give a reason but this is useful information for us)

☐ I do not want my child to receive one or both of the interventions:

Please circle which: Advice session Exercise programme Both

☐ I do not have the time to bring my child to appointments

☐ My child does not have time to take part in the study

☐ I am not happy about my child being part of a research project.

☐ Other – please state:

---

4. **If both the young person and their parents are happy to be enrolled in the study then who will provide consent?**

☐ The young person ☐ The parent

Form completed by:_____ Signature: _____

A4.4 Consent & eligibility form (controls)

Body Schema Study

PARTICIPANT CONSENT

1.	I confirm that I have read the study information sheet (dated **30/1/14, Version 2.0)**, for the above study. I have been able to think about the information, ask questions and have had these answered in a way that makes sense to me.	Please initial here
2.	I understand that I do not have to take part and that I am free to leave the study at any time without giving any reasons.	Please initial here
3.	I agree to take part in the above study.	Please initial here

PARENTAL CONSENT

1.	I confirm that I have read the study information sheet dated **20/10/15, Version 2.1** for the above study. I have had the opportunity to consider the information, ask questions and have had these answered in a way that makes sense to me.	Please initial here
2.	I understand that in giving consent for name of participant to take part in the study I am acting in his/her best interests.	Please initial here
3.	I understand that his/her participation is voluntary and that I am free to withdraw my consent at any time without giving any reasons.	Please initial here
4.	I agree to name of participant taking part in the above study.	Please initial here

OR

I do not wish to be involved in the study *(tick box on the right)*	

NAME OF PARTICIPANT	Date of Birth	Today's Date	Participant's signature

NAME OF PARENT	Today's Date	Parent's signature

PLEASE TURN OVER PAGE

Version 1.0 5 Jan 2014

If you wish to be involved in the study, can you please answer the following questions:

1. Have you ever been diagnosed with scoliosis or had spinal surgery? **Yes / No**

2. Do you suffer from any medical conditions? **Yes / No**

If yes, please describe: ……

……

……

3. Have you suffered from any injuries or conditions (including back pain) which resulted in time off school or sporting activity, or which required treatment from a doctor or other health professional, in the last 12 months? **Yes / No**

If yes, please describe what and when: ……

……

……

Please return the completed form to the school reception

If you have any queries or wish to discuss any aspect of the study, please contact:

Mr Peter Heine
Research Fellow
Warwick Clinical Trials Unit
University of Warwick
Gibbet Hill Rd
Coventry CV4 7AL

Ph: [redacted]
email: [redacted]

Thank you for your time and for considering being involved in this study.

Warwick Medical School
CLINICAL TRIALS UNIT

Participant ID:		**Centre:**	

Appendix 5 Demographic questions (cases)

Section 1:

This section is to find out some general information about you. Please answer the following questions as completely as you can.

1. Today's date:	_ _ / _ _ / _ _ _ _
2. Date of birth:	_ _ / _ _ / _ _ _ _
3. Female ☐ 1 Male ☐ 2	
4. At what age were you diagnosed with scoliosis? _ _ years old	5. Do you currently wear a brace? Yes ☐ 1 No ☐ 2

6. To which of these ethnic groups do you consider you belong? *(Please place X in one box only)*

White	☐ 1	Mixed	☐ 5
Indian	☐ 2	Pakistani	☐ 6
Bangladeshi	☐ 3	Black or Black British	☐ 7
Chinese	☐ 4	Other Ethnic Group	☐ 8

7. Onset of puberty:	
a) Girls – have you started your periods?	Yes ☐ 1 No ☐ 2
If yes, what age did they start:	_ _ years old
b) Boys – have you noticed any symptoms of puberty (i.e. pubic hair, voice changes)?	Yes ☐ 1 No ☐ 2
If yes, what age did they start:	_ _ years old

Family History

8) Do any members of your family have scoliosis (i.e. formally diagnosed by a consultant)?

Yes ☐ 1

No ☐ 2

If yes, who? *(list all that apply)* ……..……...

Section 2:

1. Please place an 'X' in the box that best describes which hand you use for each activity.

	Always Left	Usually Left	No preference	Usually Right	Always Right
Writing	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Throwing	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Scissors	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Toothbrush	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Knife (without fork)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Spoon	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Lighting a match (hand that holds match)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Computer mouse	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

This section is for your parent/guardian to complete.

The reason we ask about income is to see if we are including a broad cross-section of society in this study. We do not use the information provided here for any other purpose. The results will be averaged from all those who complete this questionnaire to give an overall picture. Individuals information will not be identifiable in any way.

1. What is your relationship to the Young Person? *(e.g. mother)* _____

2. What is your employment status? (Please place an X in the box that best applies to you).

Employed	☐ 1
Sheltered employment	☐ 2
Unemployed	☐ 3
Student	☐ 4
Housewife/husband	☐ 5
Retired	☐ 6
Other……	☐ 7

3. What is your annual income? (Please place an X in the box that best applies to you).

Up to £5,199	☐ 1
£5,200 up to £10,399	☐ 2
£10,400 up to £15,599	☐ 3
£15,600 up to 20,799	☐ 4
£20,800 up to 25,999	☐ 5
£26,000 up to £31,199	☐ 6
£31,200 up to £36,399	☐ 7
£36,400 up to £51,599	☐ 8
£52,000 and above	☐ 9
Is this before or after tax?	Before ☐ 1 After ☐ 2

6. If you have a partner: What is his/her employment status?	
Employed	☐ 1
Sheltered employment	☐ 2
Unemployed	☐ 3
Student	☐ 4
Housewife/husband	☐ 5
Retired	☐ 6
Other……	☐ 7
7. What is your partner's annual income?	
Up to £5,199	☐ 1
£5,200 up to £10,399	☐ 2
£10,400 up to £15,599	☐ 3
£15,600 up to 20,799	☐ 4
£20,800 up to 25,999	☐ 5
£26,000 up to £31,199	☐ 6
£31,200 up to £36,399	☐ 7
£36,400 up to £51,599	☐ 8
£52,000 and above	☐ 9
Is this before or after tax?	Before ☐ 1 After ☐ 2

Appendix 6 Demographic questions (controls)

Section 1:

This section is to find out some general information about you. Please answer the following questions as completely as you can.

1. Today's date:	_ _ / _ _ / _ _ _ _
2. Date of birth:	_ _ / _ _ / _ _ _ _
3. Female ☐ 1 Male ☐ 2	4. What year are you in at school/college _____

5. Home Postcode: __ __ __ __ __ __ __ __

6. Do you suffer from any medical conditions? Yes ☐ 1 No ☐ 2

If yes, please describe:

7. To which of these ethnic groups do you consider you belong? *(Please place X in one box only)*

White	☐ 1	Mixed	☐ 5
Indian	☐ 2	Pakistani	☐ 6
Bangladeshi	☐ 3	Black or Black British	☐ 7
Chinese	☐ 4	Other Ethnic Group	☐ 8

8. Onset of puberty:

a) Girls – have you started your periods?	Yes ☐ 1 No ☐ 2
If yes, what age did they start:	_ _ years old
b) Boys – have you noticed any symptoms of puberty (i.e. pubic hair, voice changes)?	Yes ☐ 1 No ☐ 2
If yes, what age did they start:	_ _ years old

Family History

9) Do any members of your family have scoliosis (i.e. formally diagnosed by a consultant)?

Yes ☐ 1

No ☐ 2

If yes, who? *(list all that apply)* ……..……...

Section 2:

1. Please place an 'X' in the box that best describes which hand you use for each activity.

	Always Left	Usually Left	No preference	Usually Right	Always Right
Writing	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Throwing	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Scissors	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Toothbrush	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Knife (without fork)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Spoon	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Lighting a match (hand that holds match)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Computer mouse	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

This section is for your parent/guardian to complete.

The reason we ask about income is to see if we are including a broad cross-section of society in this study. We do not use the information provided here for any other purpose. The results will be averaged from all those who complete this questionnaire to give an overall picture. Individuals information will not be identifiable in any way.

1. What is your relationship to the Young Person? *(e.g. mother)* _____

2. What is your employment status? (Please place an X in the box that best applies to you).

Employed	☐ 1
Sheltered employment	☐ 2
Unemployed	☐ 3
Student	☐ 4
Housewife/husband	☐ 5
Retired	☐ 6
Other……	☐ 7

3. What is your annual income? (Please place an X in the box that best applies to you).

Up to £5,199	☐ 1
£5,200 up to £10,399	☐ 2
£10,400 up to £15,599	☐ 3
£15,600 up to 20,799	☐ 4
£20,800 up to 25,999	☐ 5
£26,000 up to £31,199	☐ 6
£31,200 up to £36,399	☐ 7
£36,400 up to £51,599	☐ 8
£52,000 and above	☐ 9
Is this before or after tax?	Before ☐ 1 After ☐ 2

6. If you have a partner: What is his/her employment status?	
Employed	☐ 1
Sheltered employment	☐ 2
Unemployed	☐ 3
Student	☐ 4
Housewife/husband	☐ 5
Retired	☐ 6
Other……	☐ 7
7. What is your partner's annual income?	
Up to £5,199	☐ 1
£5,200 up to £10,399	☐ 2
£10,400 up to £15,599	☐ 3
£15,600 up to 20,799	☐ 4
£20,800 up to 25,999	☐ 5
£26,000 up to £31,199	☐ 6
£31,200 up to £36,399	☐ 7
£36,400 up to £51,599	☐ 8
£52,000 and above	☐ 9
Is this before or after tax?	Before ☐ 1 After ☐ 2

Appendix 7 X-ray information (cases)

A7.1 Case report form

Section 1: This section relates to information about the participant provided from x-ray that you will need to collect prior to the assessment appointment.

Please ensure you have entered the participant's ID number on the front cover of this form.

1. Date of x-ray

D	D		M	M		Y	Y	Y	Y

2. Curve characteristics

Type of curve (Place an X in the appropriate answer)	**Apex of curve** (specify level or levels as appropriate)	**Cobb angle** (degrees)	**Direction of curve** L = left R = right
Single ☐ 1			
Double ☐ 2			
Curve balance (Central Sacral Vertebral Line)	**Coronal plane** distance from S1 to plumb line C7 plumbline left of S1 = **L** C7 plumbline right of S1 = **R**	L / R *(please circle)*	mm
	Sagittal plane distance from S1 to plumb line C7 plumbline anterior to S1 **+ve** C7 plumbline posterior to S1 **-ve**	+ / - *(please circle)*	mm

3. Skeletal maturity

Please circle the number that indicates the Risser sign for this patient (from x-ray report).

0	1	2	3	4	5

A7.2 X-ray instructions

X-ray information

The information collected on this form will come from the participant's most recent x-ray. This information will need to be collected and recorded on the form. How this information is collected may depend on your site so this will be discussed on an individual basis. The parameters we are collecting include Cobb angle; type, direction and location of curve(s); spinal balance (sagittal and coronal); and the Risser sign.

Cobb angle

This is the standard measure of scoliosis and is an indication of the severity of the lateral curvature of the spine in the frontal plane.

Curve balance

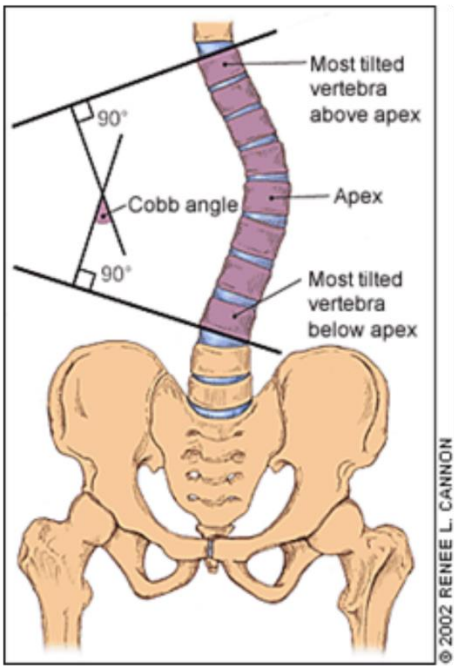
(i) Coronal plane balance

The Central Sacral Vertebral Line (CSVL) is used to measure spinal balance.

A plumb line is drawn in a vertical line downward through the centre of the C7 vertebral body. Another line is drawn up from the centre of S1. Coronal balance is evaluated by measuring the distances between these two lines in mm.

(ii) Sagittal plane balance

The sagittal balance is evaluated by measuring the distance between a line drawn up from the posterosuperior aspect of the S1 vertebral body and the plumb line down from the centre of T1.



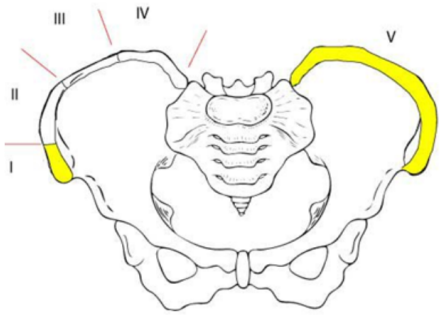
Cobb angle

(i) Coronal balance (ii) Sagittal balance

NB: absolute values of Coronal balance and Sagittal balance were calculated and used for analysis, retaining information regarding magnitude of imbalance but not the direction.

Skeletal maturity

Skeletal age can be determined by the appearance of the iliac apophysis of the pelvis. The apophysis appears laterally on a pelvic x-ray, and moves towards the spine as the patient approaches adulthood. The Risser sign measures the growth left in the spine - this may help to determine the potential for progression of scoliosis.



Risser Sign

Risser 0: ossification of the iliac crest has not begun.

Risser 1: 25% iliac apophysis ossification Anterior Superior iliac spine (anterolateral). Seen in prepuberty or early puberty.

Risser 2: 50% iliac apophysis ossification. Ossification extends halfway across iliac wing. Seen immediately before or during growth spurt.

Risser 3: 75% iliac apophysis ossification. Indicates slowing of growth.

Risser 4: 100% ossification, with no fusion to iliac crest. Indicates **slowing** of growth.

Risser 5: Iliac apophysis fuses to iliac crest. Indicates **cessation** of growth.

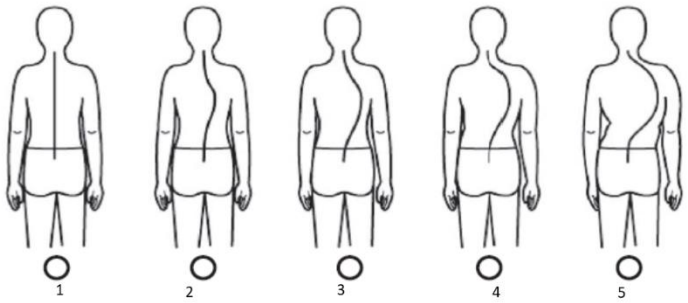
A *'Risser 0'* (before Risser 1) and Risser 5 are similar in that both show no ossification centres on x-ray. The two can be distinguished by **age** - an adolescent with Risser 5 grading will show no open growth plates in the long bones, and be older than 16 (female) or 18 (male), while a child with a *Risser 0* grading will still have open growth plates in most of the long bones and will be at the beginning of adolescence as far as age.

Appendix 8 Spinal Appearance Questionnaire (SAQ)

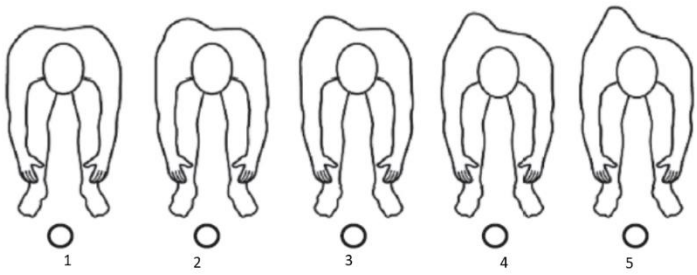
A8.1 SAQ questions

Please look carefully at the following pictures that describe spinal shapes. Please place an X in the circle below the drawing that looks most like you.

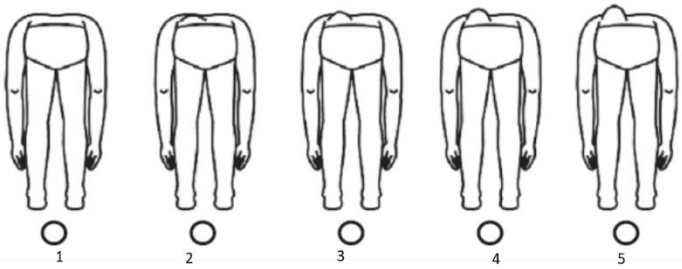
01. Body curve *(Mark only one)*



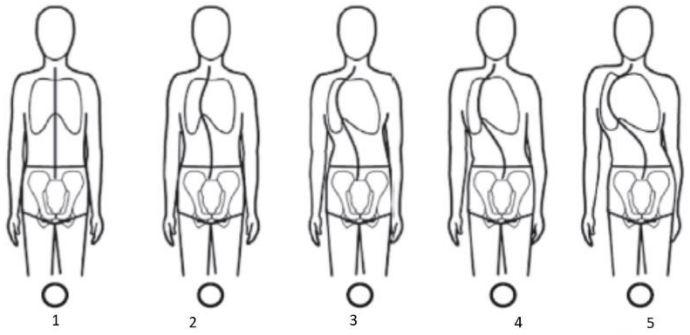
02. Rib prominence (bump) *(Mark only one)*



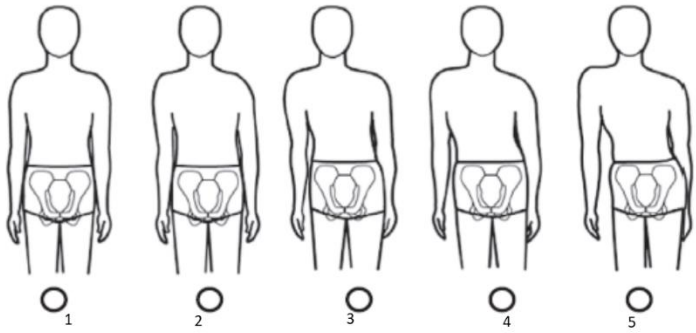
03. Flank prominence (bump) *(Mark only one)*



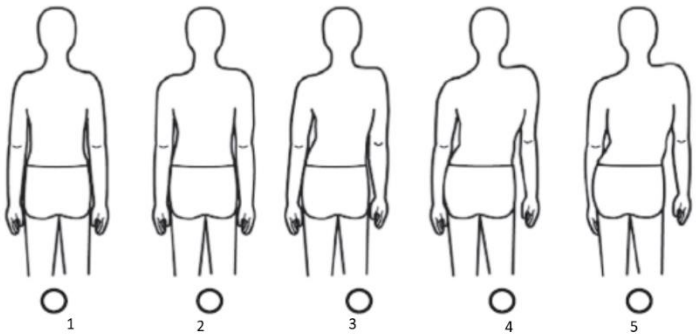
04. Head chest hips *(Mark only one)*



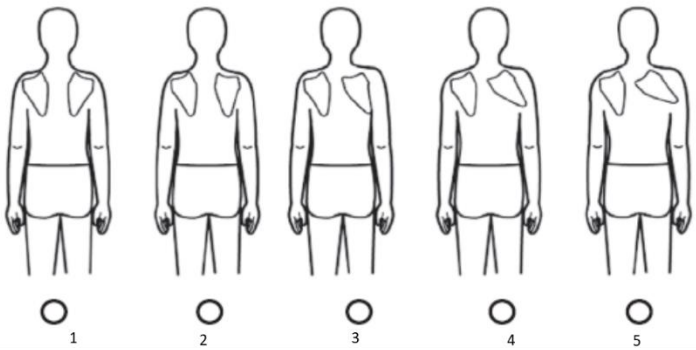
05. Position of head over hips *(Mark only one)*



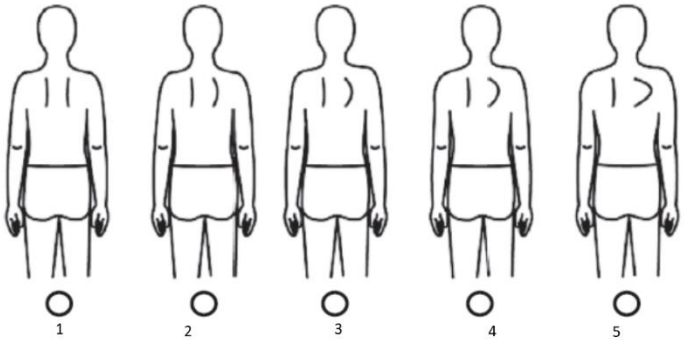
06. Shoulder level *(Mark only one)*



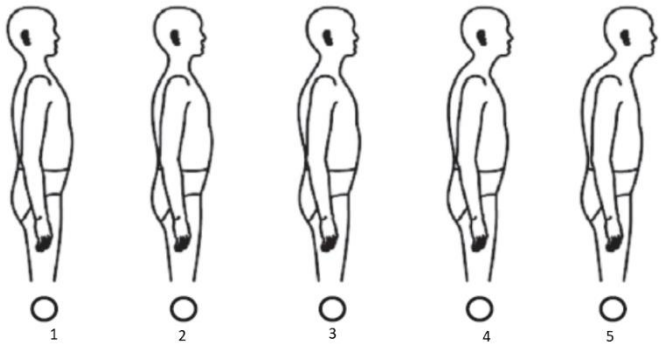
07. Shoulder blade rotation *(Mark only one)*



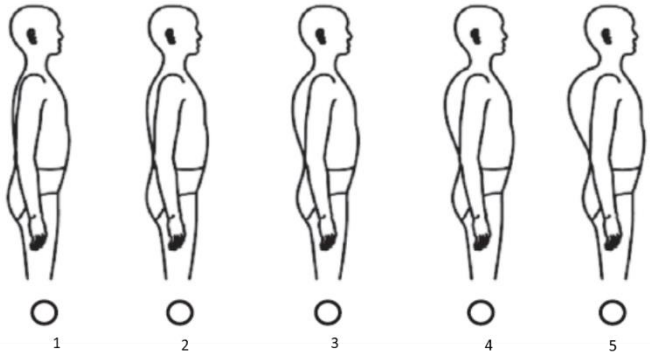
08. Shoulder angle *(Mark only one)*



09. Head position *(Mark only one)*



10. Spine prominence (bump) *(Mark only one)*



Please tell us how well the following statements apply to you. Please mark the box with an X that most applies to you.

	Not true	A little true	Somewhat true	Fairly true	Very true
11. I want to be more even.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12. I want to look better in clothes.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
13. I want to have more even hips.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14. I want to have a more even waist.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

A8.2 SAQ scoring

Appearance scale (sum of all scores)											
Score											total score = x
Question	1	2	3	4	5	6	7	8	9	10	(range = 10-50)

Expectation scale (sum of all scores)					
Score					total score = x
Question	11	12	13	14	(range = 4-20)

Score 1 - 5 each question

Lower the score the better

SAQ total score 14 (best) - 70 (worst)
Total = Appearance score + Expectations score

Appendix 9 Scoliosis Research Society questionnaire (SRS-22r)

A9.1 SRS-22r questions

INSTRUCTIONS: We are carefully evaluating the condition of your back and it is **IMPORTANT THAT YOU ANSWER EACH OF THESE QUESTIONS YOURSELF.** Please **CIRCLE THE ONE BEST ANSWER TO EACH QUESTION.**

1. Which one of the following best describes the amount of pain you have experienced during the past 6 months?

   5 None
   4 Mild
   3 Moderate
   2 Moderate to severe
   1 Severe

2. Which one of the following best describes the amount of pain you have experienced over the last month?

   5 None
   4 Mild
   3 Moderate
   2 Moderate to severe
   1 Severe

3. During the past 6 months have you been a very nervous person?

   5 None of the time
   4 A little of the time
   3 Some of the time
   2 Most of the time
   1 All of the time

4. If you had to spend the rest of your life with your back shape as it is right now, how would you feel about it?

5 Very happy
4 Somewhat happy
3 Neither happy nor unhappy
2 Somewhat unhappy
1 Very unhappy

5. What is your current level of activity?

1 Bedridden
2 Primarily no activity
3 Light labor and light sports
4 Moderate labor and moderate sports
5 Full activities without restriction

6. How do you look in clothes?

5 Very good
4 Good
3 Fair
2 Bad
1 Very bad

7. In the past 6 months have you felt so down in the dumps that nothing could cheer you up?

1 Very often
2 Often
3 Sometimes
4 Rarely
5 Never

8. Do you experience back pain when at rest?

1 Very often
2 Often
3 Sometimes
4 Rarely
5 Never

9. What is your current level of work/school activity?

5 100% normal
4 75% normal
3 50% normal
2 25% normal
1 0% normal

10. Which of the following best describes the appearance of your trunk; defined as the human body except for the head and extremities?

5 Very good
4 Good
3 Fair
2 Poor
1 Very Poor

11. Which one of the following best describes your pain medication use for back pain?

5 None
4 Non-narcotics weekly or less (e.g., aspirin, Tylenol, Ibuprofen)
3 Non-narcotics daily
2 Narcotics weekly or less (e.g. Tylenol III, Lorcet, Percocet)
1 Narcotics daily

12. Does your back limit your ability to do things around the house?

5 Never
4 Rarely
3 Sometimes
2 Often
1 Very Often

13. Have you felt calm and peaceful during the past 6 months?

5 All of the time
4 Most of the time
3 Some of the time
2 A little of the time
1 None of the time

14. Do you feel that your back condition affects your personal relationships?

5 None
4 Slightly
3 Mildly
2 Moderately
1 Severely

15. Are you and/or your family experiencing financial difficulties because of your back?

1 Severely
2 Moderately
3 Mildly
4 Slightly
5 None

16. In the past 6 months have you felt down hearted and blue?

5 Never
4 Rarely
3 Sometimes
2 Often
1 Very often

17. In the last 3 months have you taken any days off of work, including household work, or school because of bac pain?

5 0 days
4 1 day
3 2 days
2 3 days
1 4 or more days

18. Does your back condition limit your going out with friends/family?

5 Never
4 Rarely
3 Sometimes
2 Often
1 Very often

19. Do you feel attractive with your current back condition?

5 Yes, very
4 Yes, somewhat
3 Neither attractive nor unattractive
2 No, not very much
1 No, not at all

20. Have you been a happy person during the past 6 months?

1 None of the time
2 A little of the time
3 Some of the time
4 Most of the time
5 All of the time

21. Are you satisfied with the results of your back management?

5 Very satisfied
4 Satisfied
3 Neither satisfied nor unsatisfied
2 Unsatisfied
1 Very unsatisfied

22. Would you have the same management again if you had the same condition?

5 Definitely yes
4 Probably yes
3 Not sure
2 Probably not
1 Definitely not

Thank you for completing this questionnaire. Please comment if you wish.

A9.2 SRS-22r scoring (example)

DOMAIN	(Score 5 Best- 1 Worst)					Sum of Responses A	# Questions Answered (Possible) B	Mean Score[+++] A ÷B
Function	3 (5[+])	4 (9)	3 (12)	x (15)	2 (18)	12	4 (~~5~~)	3
Pain	2 (1)	4 (2)	4 (8)	1 (11)	1 (17)	12	5 (5)	2.4
Self image	3 (4)	3 (6)	3 (10)	4 (14)	4 (19)	17	5 (5)	3.4
Mental health[++]	4 (3)	4 (7)	3 (13)	4 (16)	4 (20)	19	5 (5)	3.8
				SUB TOTAL		60	19 (~~20~~)	3.16
Satisfaction/Dissatisfaction with management				4 (21)	4 (22)	8	2 (2)	4
				TOTAL		68	21 (~~22~~)	3.24

[+]Question number
[++]Questions adopted with permission from SF-36
[+++]Mean Score 5 Best-1 Worst

SCORING INSTRUCTIONS:
Unanswered questions-reduce questions answered denominator by appropriate number
Delete questions with more than one response
Domain can't be scored if fewer than 3 questions answered.

Appendix 10 EuroQol EQ5D-3L

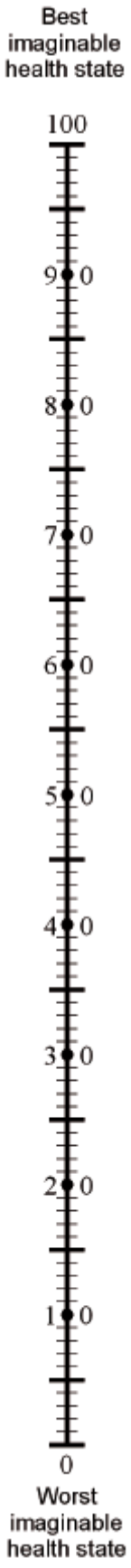
Mobility	
I have no problems in walking about	1
I have some problems in walking about	2
I am confined to bed	3
Self-care	
I have no problems with self-care	1
I have some problems washing or dressing myself	2
I am unable to wash or dress myself	3
Usual activities	
I have no problems with performing my usual activities	1
I have some problems with performing my usual activities	2
I am unable to perform my usual activities	3
Pain/discomfort	
I have no pain or discomfort	1
I have moderate pain or discomfort	2
I have extreme pain or discomfort	3
Anxiety/depression	
I am not anxious or depressed	1
I am moderately anxious or depressed	2
I am extremely anxious or depressed	3

To help people say how good or bad a health state is, we have drawn a scale (rather like a Thermometer) on which the best state you can imagine is marked by 100 and the worst state you can imagine is marked by 0.

We would like you to indicate on this scale **how good or bad is your own health today, in your opinion.**

Please do this by drawing a line from the box below, to whichever point on the scale indicates how good or bad your current health state is **today**.

Your own health state TODAY



Appendix 11 Paediatric Outcomes Data Collection (PODCI)

A11.1 PODCI questions

Q1	During last week, easy/hard to: Lift heavy books?	1 = Easy 2=A little hard 3 = Very hard 4=Cant do at all
Q2	During last week, easy/hard to: Pour a half gallon of milk?	
Q3	During last week, easy/hard to: Open a jar that has been opened before?	
Q4	During last week, easy/hard to: Use a fork and spoon?	
Q5	During last week, easy/hard to: Comb your hair?	
Q6	During last week, easy/hard to: Button buttons?	
Q7	During last week, easy/hard to: Put on your coat?	
Q8	During last week, easy/hard to: Write with a pencil?	
Q9	Over the last 12 months, how often did you miss school because of health?	1 = Rarely 2 = x1/month 3 = x2-3/month 4 = x1/week 5 = >x1/week 6 = not student
Q10	During last week, how happy with: looks?	1 = Very happy 2 = Somewhat happy 3 = Not sure 4 = Somewhat unhappy 5 = Very unhappy
Q11	During last week, how happy with: body?	
Q12	During last week, how happy with: clothes or shoes can wear?	
Q13	During last week, how happy with: ability to do the same things friends do?	
Q14	During last week, how happy with: health in general?	
Q15	During last week, how often: feel sick and tired?	1 = Most of the time 2 = Some of the time 3 = A little of the time 4 = None of the time
Q16	During last week, how often: full of pep and energy?	
Q17	During last week, how often: pain or discomfort interfere with activities?	
Q18	During last week, easy/hard to: Run short distances?	1 = Easy 2 = A little hard 3 = Very hard 4 = Cant do at all
Q19	During last week, easy/hard to: Bicycle or tricycle?	
Q20	During last week, easy/hard to: Climb three flights of stairs?	
Q21	During last week, easy/hard to: Climb one flight of stairs?	
Q22	During last week, easy/hard to: Walk more than a mile?	
Q23	During last week, easy/hard to: Walk three blocks?	
Q24	During last week, easy/hard to: Walk one block?	
Q25	During last week, easy/hard to: Get on and off a bus?	
Q26	How often need help from another person for walking and climbing?	1 = Never 2 = Sometimes 3 = About half the time 4 = Often 5 = All the time
Q27	How often use assistive devices for walking and climbing?	

Q28	During last week, easy/hard to: Stand while washing hands and face at a sink?	1 = Easy 2 = A little hard 3 = Very hard 4 = Cant do at all
Q29	During last week, easy/hard to: Sit in a regular chair without holding on?	
Q30	During last week, easy/hard to: Get on and off a toilet or chair?	
Q31	During last week, easy/hard to: Get in and out of bed?	
Q32	During last week, easy/hard to: Turn door knobs?	
Q33	During last week, easy/hard to: Bend over from a standing position and pick up something off the floor?	
Q34	How often need help from another person for sitting and standing?	1 = Never 2 = Sometimes 3 = About half the time 4 = Often 5 = All the time
Q35	How often use assistive devices for sitting and standing?	
Q36	Participate in recreational outdoor activities with other kids the same age?	1 = Yes easily 2 = Yes but a little hard 3 = Yes but very hard 4 = No
Q37	Was activity limited by: Pain?	1 = Yes leave blank if not circled
Q38	Was activity limited by: General Health?	
Q39	Was activity limited by: Doctor or parent instructions?	
Q40	Was activity limited by: Fear the other kids won't like you?	
Q41	Was activity limited by: Dislike of recreational outdoor activities?	
Q42	Was activity limited by: Activity not in season?	
Q43	Participate in pickup games or sports with other kids the same age?	1 = Yes easily 2 = Yes but a little hard 3 = Yes but very hard 4 = No
Q44	Was activity limited by: Pain?	1 = Yes leave blank if not circled
Q45	Was activity limited by: General Health?	
Q46	Was activity limited by: Doctor or parent instructions?	
Q47	Was activity limited by: Fear the other kids won't like you?	
Q48	Was activity limited by: Dislike of pickup games or sports?	
Q49	Was activity limited by: Activity not in season?	
Q50	Participate in competitive level sports with other kids the same age?	1 = Yes easily 2 = Yes but a little hard 3 = Yes but very hard 4 = No
Q51	Was activity limited by: Pain?	1 = Yes leave blank if not circled
Q52	Was activity limited by: General Health?	
Q53	Was activity limited by: Doctor or parent instructions?	
Q54	Was activity limited by: Fear the other kids won't like you?	
Q55	Was activity limited by: Dislike of competitive level sports?	
Q56	Was activity limited by: Activity not in season?	
Q57	How often in last week did you get together and do things with friends?	1 = Often 2 = Sometimes 3 = Never or rarely
Q58	Was activity limited by: Pain?	1 = Yes leave blank if not circled
Q59	Was activity limited by: General Health?	
Q60	Was activity limited by: Doctor or parent instructions?	
Q61	Was activity limited by: Fear the other kids won't like you?	
Q62	Was activity limited by: Friends not around?	

Q63	How often in last week did child participate in gym/recess?	1 = Often 2 = Sometimes 3 = Never or rarely 4 = No gym or recess
Q64	Was activity limited by: Pain?	1 = Yes leave blank if not circled
Q65	Was activity limited by: General Health?	
Q66	Was activity limited by: Doctor or parent instructions?	
Q67	Was activity limited by: Fear the other kids won't like you?	
Q68	Was activity limited by: Dislike of gym/recess?	
Q69	Was activity limited by: School not in session?	
Q70	Was activity limited by: Does not attend school?	
Q71	Is it easy or hard to make friends with kids own age?	1 = Usually easy 2 = Sometimes easy 3 = Sometimes hard 4 = Usually hard
Q72	How much pain during the last week?	1 = None 2 = Very mild 3 = Mild 4 = Moderate 5 = Severe 6 = Very severe
Q73	During last week, how much did pain interfere with normal activities	1 = Not at all 2 = A little bit 3 = Moderately 4 = Quite a bit 5 = Extremely
Q74	Expectation of Treatment: To have pain relief.	1=Definitely yes 2=Probably yes 3=Not sure 4=Probably not 5=Definitely not
Q75	Expectation of Treatment: To look better.	
Q76	Expectation of Treatment: To feel better about self.	
Q77	Expectation of Treatment: To sleep more comfortably.	
Q78	Expectation of Treatment: To be able to do activities at home.	
Q79	Expectation of Treatment: To be able to do more at school.	
Q80	Expectation of Treatment: To be able to do more play or recreational activities.	
Q81	Expectation of Treatment: To be able to do more sports.	
Q82	Expectation of Treatment: To be free from pain or disability as an adult.	
Q83	If had to spend the rest of your life with your bone and muscle condition as it is right now, how would you feel about it?	1 = Very satisfied 2 = Somewhat satisfied 3 = Neutral 4 = Somewhat dissatisfied 5 = Very dissatisfied

A11.2 PODCI scoring

Upper extremity and physical function scale		
Notes:	A minimum of 4 items must have valid answers to score this scale.	
Mean of Items:	(sum of items Q1, Q2, Q3, Q4, Q5, Q6, Q8, Q32/ (number of non-missing items)	1 to 4
Standardized Score:	[(4 - mean of items) / 3] * 100	0 to 100
Transfer and basic mobility scale		
Notes:	A minimum of **7** items must have valid answers to score this scale.	
	Q34 is RESCALED as follows: Q34rescaled = [(Q34 - 1)* 3/4] + 1	1 to 4
	Q35 is RESCALED as follows: Q35rescaled = [(Q35 - 1)* 3/4] + 1	1 to 4
Mean of Items:	(sum of items Q7, Q21, Q24, Q25, Q28, Q29, Q30, Q31, Q33, Q34Rescaled, Q35Rescaled) / (number of non-m	1 to 4
Standardized Score:	[(4 - mean of items) / 3] * 100	0 to 100
Sports and physical functioning scale		
Notes:	A minimum of 6 items must have valid answers to score this scale.	
	Q26 is RESCALED as follows: Q26rescaled = [(Q26 -1) * 3/4] + 1	1 to 4
	Q27 is RESCALED as follows: Q27rescaled = [(Q27 -1) * 3/4] + 1	1 to 4
	Q36 is RECODED to MISSING if (Q36 = 4 and [Q42 = 1)	1 to 4
	Q43 is RECODED to MISSING if (Q43 = 4 and Q49 =1)	1 to 4
	Q50 is RECODED to MISSING if (Q50 = 4 and Q59 = 1)	1 to 4
	Q57 is RECODED and RESCALED as follows:	
	Step #1: Q57 is RECODED to MISSING if (Q57 = 3 and Q62 = 1)	
	Step #2: If Q57 is not missing, Q57rescaled = [(Q57 -1) * 3/2] + 1	1 to 4
	Q63 is RECODED and RESCALED as follows:	
	Step #1: Q63 is RECODED to MISSING if (Q63 = 4)	
	Step #2: Q63 is RECODED to MISSING if (Q63 = 3 and EITHER [Q69 = 1] or [Q70 = 1])	
	Step #3: If Q63 is not missing, Q63rescaled = [(Q63 - 1) * 3/2] + 1	1 to 4
Mean of Items:	(sum of items Q18, Q19, Q20, Q22, Q23, Q26rescaled, Q27rescaled, Q36, Q43, Q50, Q57rescaled, Q63rescaled) / (numbe	1 to 4
Standardized Score:	[(4 - mean of items) / 3] * 100	0 to 100

Pain/comfort scale		
Notes:	A minimum of 2 items must have valid answers to score this scale.	
	Q17 is RESCALED as follows: Q17rescaled = [(4 - Q17) * 4/3] + 1	1 to 5
	Q72 is RESCALED as follows: Q73rescaled = [(Q73 - 1) * 4/5] + 1	1 to 5
Mean of Items:	(sum of items Q17rescaled, Q72rescaled, Q73) / (number of non-missing items)	1 to 5
Standardized Score:	[(4 - {mean of items - 1}) / 4] * 100	0 to 100
Happiness scale		
Notes:	A minimum of 3 items must have valid answers to score this scale.	
Mean of Items:	(sum of items Q10, Q11, Q12, Q13, Q14) / (number of non-missing items)	1 to 5
Standardized Score:	[(5 - mean of items) / 4] * 100	0 to 100
Global Function scale		
Notes:	If ANY of the four relevant scales are missing, this is not calculated.	
Mean of Items:	(sum of "Mean of Items" values for scales: 'Upper extremity and physical function' + 'Transfer and basic mobility' + 'Sports and physical function' and 'Pain/comfort') / 4	0 to 100

Appendix 12 Kinaesthetic & proprioceptive questionnaire (KPAQ)

A12.1 KPAQ questions

Listed below are a number of statements related to a variety of normal kinds of feelings and bodily reactions. Read each item and decide how well the statement reflects you personally. It's best to go with your first judgement and not to spend too long thinking about any one question.
Place a 'X' in the box that most applies to you.

	Never true	Occasionally true	Sometimes true	Frequently true	Always true
1. I am aware of my overall body posture.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2. I am aware of how far I am bending over when I have to bend to do something.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3. I am aware of strain in my muscles.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4. I can provide definite information regarding the specific location and severity of pain/ discomfort in my body when the doctor asks me what symptoms I am having.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5. I can exert the correct amount of force/ pressure required to do a task even without thinking about it.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6. I am sensitive to changes in the position of my legs even without looking at them.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7. I can touch my nose with my index fingers, even with my eyes closed.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8. I can tell when I should stop doing some-thing (e.g. lifting) before it causes me pain or injury.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9. I can tell where my hands are located without even looking at them.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10. I can tell how tired I will be after a task when I first start doing it.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11. I can feel even the slightest touch (e.g. a small raindrop or an ant crawling) on my skin.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12. I know my own strength.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

A12.2 KPAQ scoring

KPAQ score = sum of all scores 12 (worst) to 60 (best)

Appendix 13 Marking up instructions

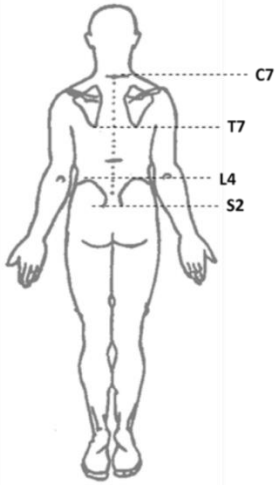
Location of apex (point 8) e.g. T4

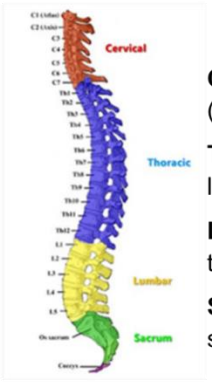
to indicate which part of the spine the localisation & 2 point discrimination tests occur

Remember to mark the points on the back prior to testing in sections 7 & 8.

See the Skin marking protocol in the manual for full details.

- Using whichever landmark is easiest from the list below, count up or down to find this point.
- Remember, there are 5 Lumbar, 12 thoracic & 7 cervical vertebrae.





C7 = most prominent point at base of neck (doesn't disappear on extension).

T7 = at same level as bottom point of scapulae

L4 = at same level (or just above) as line between both iliac crests.

S2 = same level as the PSIS (dimples either side of base of spine)

- Once identified, mark out the testing points using the template.

NB: For controls, the above procedures were repeated using the same vertebral level as their matching cases.

Appendix 14 Two point discrimination testing (TPDT)

A14.1 TPDT case report form

site **Right**

test order	**22**	**19**	**11**	**15**	**2**	**5**	**12**	**6**	**17**	**23**	**3**	**9**	**10**	**8**	**13**	**14**	**21**	**4**	**20**	**18**	**7**	**1**	**16**
distance	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	55mm	60mm	65mm	70mm	75mm	80mm	85mm	90mm	95mm	100mm	100mm	100mm	1 point	1 point
trial 1																							
trial 2																							
trial 3																							

site **Left**

test order	**20**	**16**	**9**	**7**	**23**	**6**	**13**	**8**	**5**	**4**	**10**	**2**	**19**	**22**	**21**	**11**	**17**	**3**	**12**	**1**	**15**	**18**	**14**
distance	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	55mm	60mm	65mm	70mm	75mm	80mm	85mm	90mm	95mm	100mm	100mm	100mm	1 point	1 point
trial 1																							
trial 2																							
trial 3																							

A14.2 TPDT instructions

Two point discrimination

Equipment:

Two-point discriminator (calipers) tool

Set up:

1) Patient lying face down on plinth with face looking through face hole. Place flat pillow under stomach.
2) Patient´s back marked up as previously described using template.

Procedure:

1) Show the patient the discriminator tool and give instructions as to what you will be asking them to do (i.e. guess whether they are being touched by one or two points).
2) Do a practice by touching them randomly with one or two points on any part of the arm or leg. Apply pressure until the very first blanching of the skin for one second - repeat 3 times. Ensure that both points are contacting skin at the same time (NB: the patient is to tell you if they feel two points because the points touched at different times). Ask the patient to guess by saying 'one' or 'two' depending on their perception. If they are unsure, you can repeat the procedure once.
3) For actual test, two point discrimination will be conducted at 2 different sites (points 7 & 9). The testing order of sites is provided on the result sheet of this form. Test the first site completely and then test the other site. Testing will take place in 5 mm increments between 10mm and 100mm. The actual order of testing for each distance is randomised (see result sheet).
5) **Trial 1:** Ensure the tool is held parallel to the spine. Test each distance at first site in the order given on the result sheet. Record '1' or '2' in the box underneath for Trial 1. As you look along the row of results for Trial 1, there should be a pattern of 1s at the beginning of the sequence, 2's at the end of the sequence, and possibly a mix of 1's and 2s in the middle

   Trial 2: Re-measure the values between the last two consecutive 1s and the first 2 consecutive 2s

Trial 1	1	1	1	1	1	1	1	2	1	2	1	1	2	2	1	2	2	2	2	2	2	2	2

   inclusive (see example above).

   Trial 3: Repeat same measures as Trial 2 (see example below).

Trial 1	1	1	1	1	1	1	1	2	1	2	1	1	2	2	1	2	2	2	2	2	2	2	2
Trial 2									→	→	→	→	→										
Trial 3									←	←	←	←	←										

Instructions:

"I am going to tap you on your back 3 times with either one or two points on this device. I want you to tell me whether it is one or two points. I will repeat this many times. If you are not sure I can repeat it."

"I am going to start now - please say 'one' when you feel one point and 'two' if you feel two points."

A14.3 TPDT scoring

Threshold distances (mm) established from review of case report form. Threshold distance is the distance-between-points of the caliper at which the participant first is able to correctly distinguish two points as opposed to one point.

Appendix 15 Localisation

A15.1 Localisation case report form

Location														
5	**1**	**8**	**11**	**7**	**2**	**15**	**9**	**4**	**10**	**3**	**13**	**14**	**6**	**12**
15	**1**	**8**	**10**	**5**	**2**	**4**	**7**	**9**	**14**	**3**	**13**	**12**	**11**	**6**

A15.2 Localisation instructions

Localisation

Equipment:

Monofilament 10g

Chart showing skin markings 1-15 (use chart appropriate to location of curve apex)

Set up:

1) Patient lying face down on plinth with face looking through face hole. Place flat pillow under stomach.

2) Patient´s back marked up as previously described with 15 testing locations.

Procedure:

1) Show the patient the chart and give instructions as to what you will be asking them to do (i.e. guess which site has been touched). Leave the chart so they can see it throughout test.

2) As a test, touch each site in turn (1-15) and identify them to the patient. Apply pressure until the wire first bends for one second. Repeat 3 times in a row.

3) For actual test, each site will be tested twice in random order. The testing order of sites are provided on the result sheet of this form (see next page).

Measurement:

Ask the patient to guess the location - record reported location in box under actual location.

12	7	3	13	15	5	8	1	14	11	2	10	9	4	6
12	6	3	14	15	5	8	2	14	12	2	11	9	4	5

Instructions:

"Look at the chart with all the numbers on it. I am going to touch you on your back in these different places and I want you to try and guess which number it is. Each place will be touched more than once. You have only one chance to guess each time - if you are not sure, say the number you think is closest to the place where you feel the touch."

"I am going to start now - please tell me which location you think they are by saying the number from the sheet in front of you."

A15.3 Localisation scoring

The number of correct responses was counted from 15 different stimulus locations. Each location was tested twice resulting in a maximum possible score of 30 correct responses.

For side to side comparisons, only the results of 12 points were used with the central locations omitted (locations 3, 8, 13). This resulted in 6 locations per test and a maximum possible score of 12 for each side.

Appendix 16 Laterality discrimination instructions

Laterality discrimination (Recognise programme)

Equipment:

Computer with internet access

Set up:

Patient sitting at table/desk in front of computer.

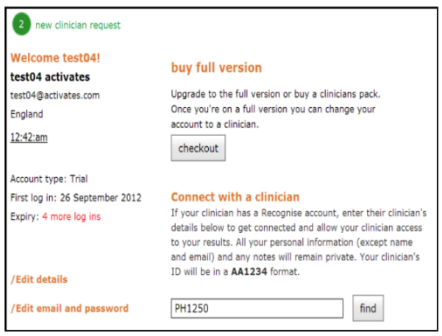
Procedure:

1) Connect to the internet and navigate to the NOI Recognise website (www.noigroup.com/recognise).

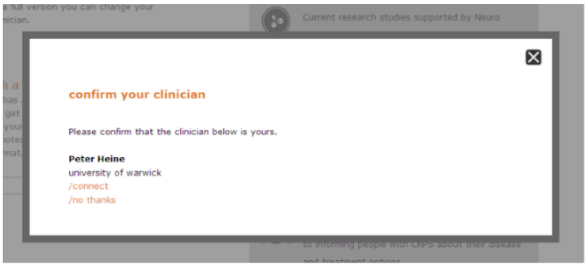
2) Login using 3-digit participant ID number (e.g. 004@activates.com)

Enter password

Enter 'xxxxxx' in 'Connect with a clinician' box.



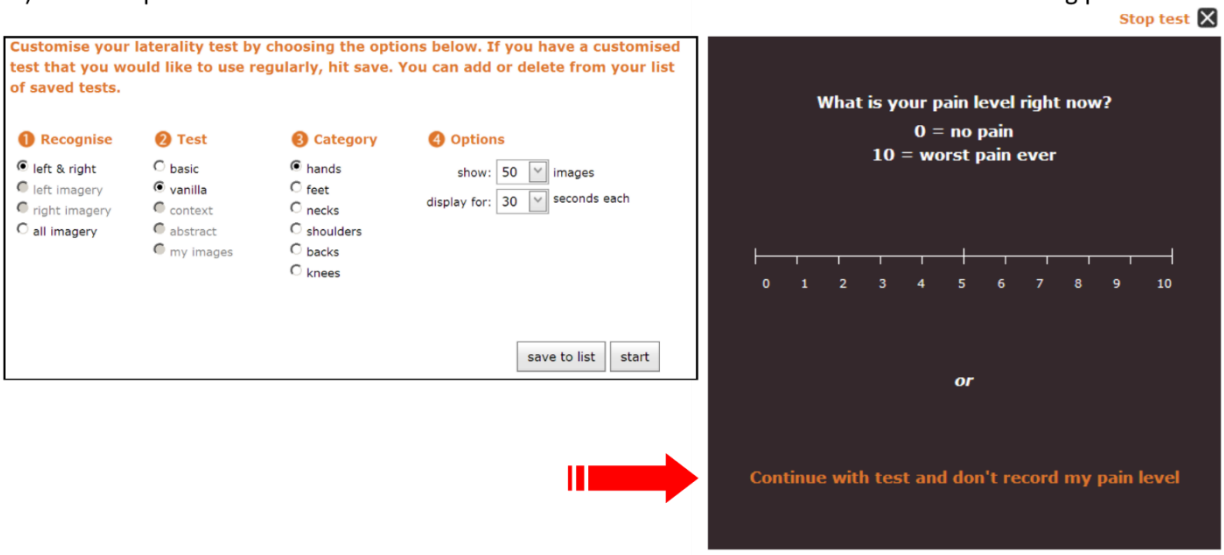
3) Click '/connect' to confirm clinician. Click on recognise' in menu top right of screen.



4) Choose options for hand or back test as detailed in appropriate pages. Both the hands and the back will have two trials of 50 images each.

Hands

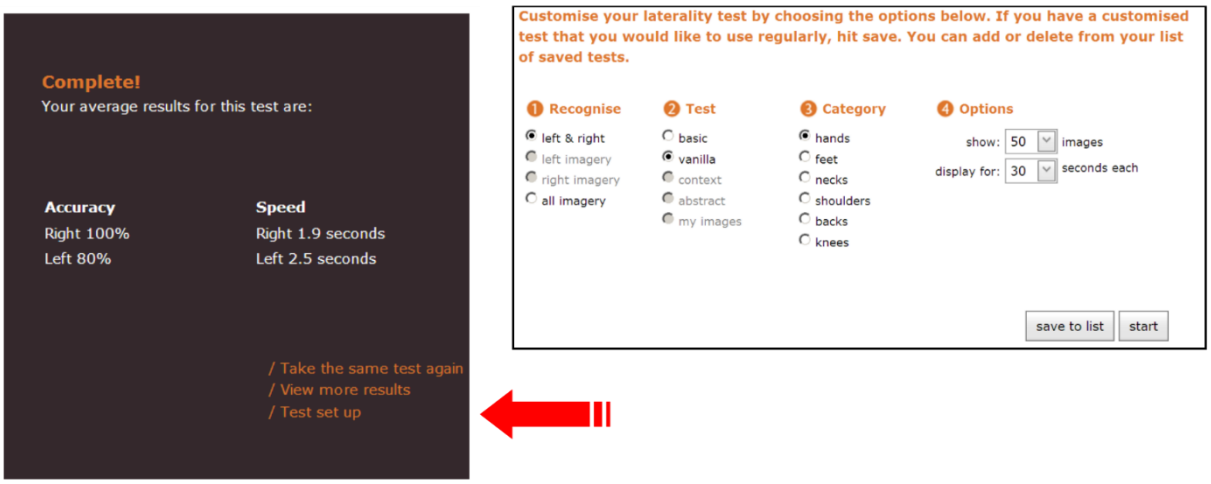
1) Choose options as shown below and then click 'start'. Choose to continue without recording pain level.



2) Ask participant to read instructions and complete test. They have to decide whether the image shown is the left or the right hand. They will be provided with the results at the end of the test. The computer will also time how long it takes them to make a decision. They have to make their decisions as accurately and as fast as possible.

3) At end of test, the following results box will be displayed.

Click on 'test set-up' and repeat test with same conditions as before.



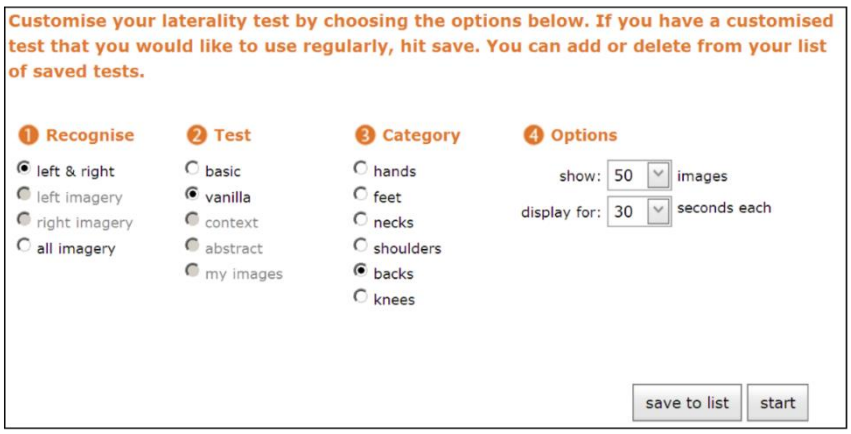
4) At end of 2nd trial, click on 'test set-up' for the back test. See instructions for set-up on next page.

Back

1) click on 'test set-up' to set up for the back test.

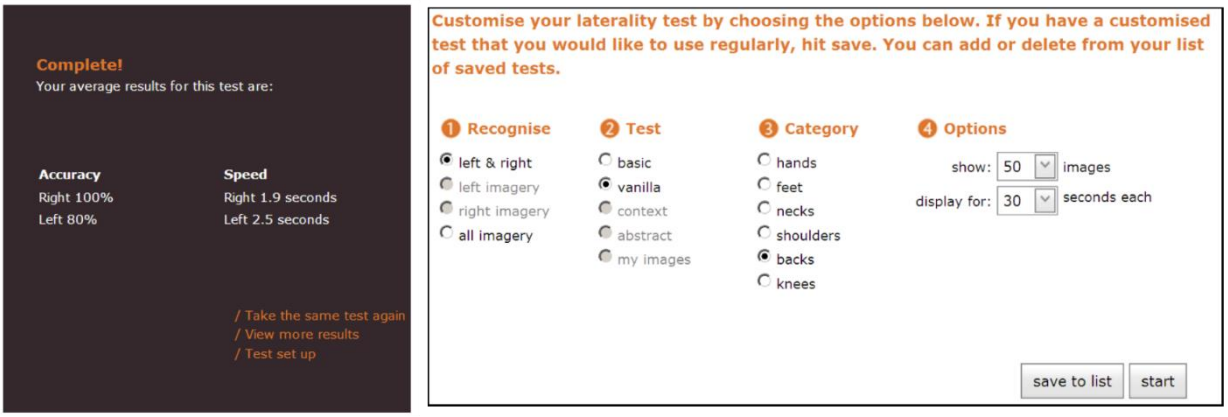
This time, rather than which side is displayed, the patient has to decide in which direction the body is moving. For example, are they turning or bending to the right or left.

Click 'start'.

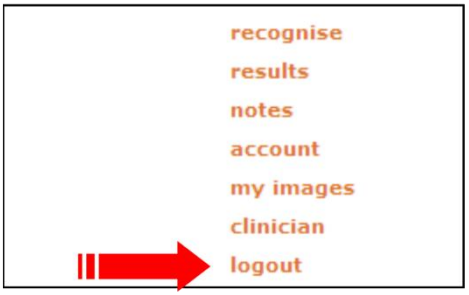


2) At end of test, the following results box will be displayed.

Click on 'test set-up' and repeat test with same conditions as before.



3) At end of 2nd trial, click on 'logout' in menu top right of screen.



Instructions:

Hand test - Left or Right hand

“When you start the programme, there will be a series of images of the hand in different positions. I want you to try and guess whether it is the left or the right hand. Press the appropriate key on the keyboard to make your choice. You only get one chance for each picture. The computer will tell you at the end how many you got correct. It will also time you to see how long it takes to make your decision. Try to do the test as quickly and accurately as possible .”

“Follow the instructions on the screen.”

Trunk Test - moving towards the Left or Right

“When you start the programme, there will be a series of images of the trunk in different positions. I want you to try and guess in which direction the body is moving - is it bending or twisting to the left or to the right. Press the appropriate key on the keyboard to make your choice. You only get one chance for each picture. The computer will tell you at the end how many you got correct. It will also time you to see how long it takes to make your decision. Try to do the test as quickly and accurately as possible .”

“Follow the instructions on the screen.”

A16.1 Laterality scoring

Each test consisted of 50 images, 25 of which were of the left and 25 of the right side. Testing was performed twice for images of the back and the hands resulting in 100 images per body part. Correct responses were counted and converted to an overall percentage accuracy. Time (ms) was recorded for both the incorrect and incorrect responses for each image.

Appendix 17 Proprioception

A17.1 Proprioception case report form

Right

Max Right	*Please **'zero'** the device in neutral.*	**Max side flexion Right** degrees		
1 **1/2 Right**	*Please **'zero'** the device in neutral.*	**1/2 Right** **1.1** degrees	*Return to neutral* *&* *then repeat*	**1/2 Right** **1.2** degrees
2 **1/2 Right**	*Please **'zero'** the device in neutral.*	**1/2 Right** **2.1** degrees	*Return to neutral* *&* *then repeat*	**1/2 Right** **2.2** degrees
3 **1/2 Right**	*Please **'zero'** the device in neutral.*	**1/2 Right** **3.1** degrees	*Return to neutral* *&* *then repeat*	**1/2 Right** **3.2** degrees

Left

Max Left	*Please **'zero'** the device in neutral.*	**Max side flexion Left**		
		degrees		
1 **1/2 Left**	*Please **'zero'** the device in neutral.*	**1/2 Left** **1.1**	*Return to neutral* *&* *then repeat*	**1/2 Left** **1.2**
		degrees		degrees
2 **1/2 Left**	*Please **'zero'** the device in neutral.*	**1/2 Left** **2.1**	*Return to neutral* *&* *then repeat*	**1/2 Left** **2.2**
		degrees		degrees
3 **1/2 Left**	*Please **'zero'** the device in neutral.*	**1/2 Left** **3.1**	*Return to neutral* *&* *then repeat*	**1/2 Left** **3.2**
		degrees		degrees

A17.2 Proprioception instructions

Position matching

Equipment:

Inclinometer

Blindfold goggles

Eyeliner pencil or similar (to mark measuring point)

Set up:

1) Patient sitting on stool or bed (no back or arm rest) with feet flat on floor and arms crossed across chest so fingers are touching opposite shoulders.
2) Mark measuring position on skin at C7/T1 (see skin marking protocol for locating this point). Draw a line perpendicular to the spine through this point. You will use this to align the inclinometer when measuring.
3) Place blindfold goggles on patient and ensure they cannot see.

Procedure:

Do a practice to familiarise the patient with the test procedure.

Maximum Side Flexion

1) Ask patient to sit in upright position facing straight ahead with arms crossed over chest. Place the inclinometer against the skin marker at C7 and 'zero' the device.
2) Ask the patient to bend to one side as far as possible while keeping their legs and hips still. Measure the angle and record to nearest degree.

1/2 side flexion

1) Instruct patient as to the testing procedure (i.e. attempting to match 1/2 way position).
2) Use the same setup as previously.
3) In upright position, place the device and zero it.
4) Ask patient to bend sideways slowly to what they consider to be 1/2 of their full side flexion ROM. Ask the patient to hold this position and to 'memorise' it. Measure the angle to the nearest degree and record it. Instruct them that the aim is to return to this 1/2 way position.
5) Return to start position.
6) Ask patient to return to their '1/2 way' position. Re-measure and record the angle on the display.
7) Repeat this 3 times for that side.

Repeat the above procedures for the other side. The actual order of testing has been randomised (see results table).

Position matching ctd

Instructions:

Max ROM

“Sit comfortably with your arms across your chest like this. I will put a blindfold over your eyes so you can’t see. ”

“To start, you need to face straight ahead and sit comfortably - this is your start position. When I say go back to the start, this is the position you need to return to.”

“I will ask you to bend to the side as far as you can and then return to sitting straight. I will be looking at the device and writing down how far you bend. To give me time to write them down, you need to stay in the position until I say.”

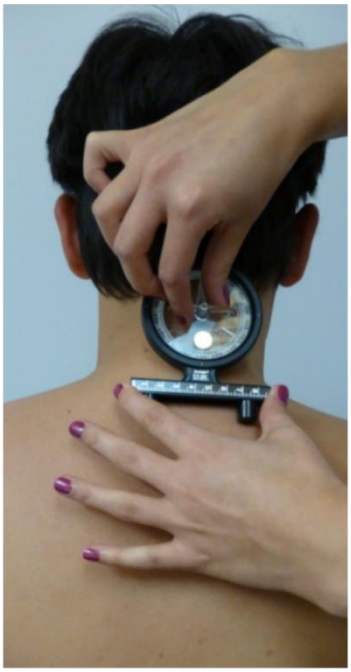
“Bend your head and body together as far to the [L/R] as possible - hold that position. Return to the start position.”

1/2 ROM

“Now I want you to bend your body to the [L/R] to a point you think is 1/2 way between the start position and the furthest you can go - hold that position. I want you to memorise this position because I am going to ask you to repeat it.”

“Return to the start position - now try and go back to the 1/2 way position again.”

1. mark the position of C7.



2. place the device on the line & zero inclinometer.

3. measure & record the angle at either full or 1/2 side flexion.

A17.3 Proprioception scoring

Testing was performed 3 times to the left and right sides. The angle of the true reference position and the perceived matching position were measured on each occasion. The difference or error (degrees) was calculated according to:

Error (degrees) = true position (degs) - perceived position (degrees)

Negative distances indicate that the perceived position was an overestimation (i.e. greater angle) of the true position.

Errors were converted to absolute values (AE) to calculate the magnitude of error irrespective of whether it was an under or over-estimation by:

Absolute error (degrees) = $\sqrt{(error^2)}$

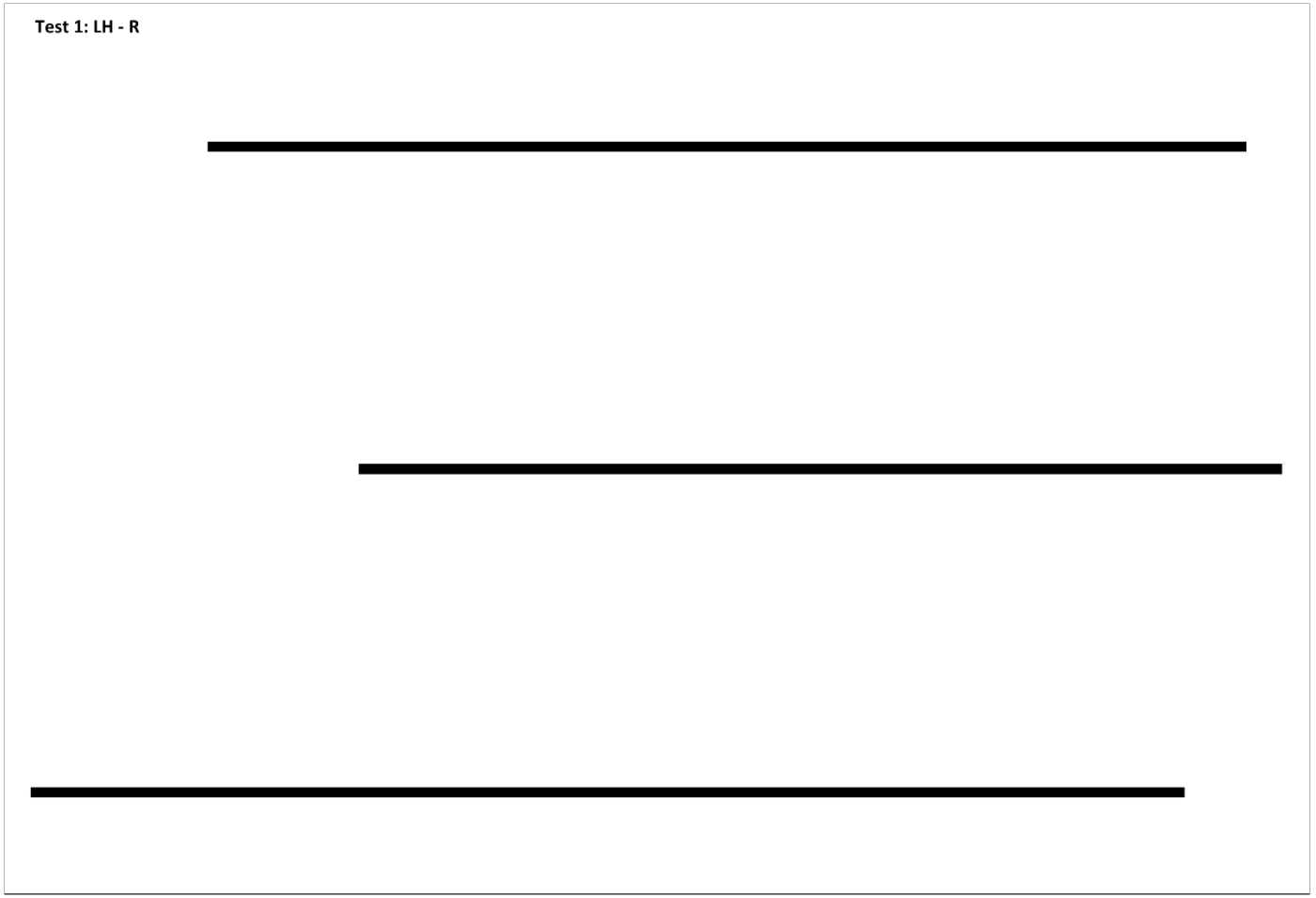
To adjust for the differences between subjects with regard to the angle of the reference positon, the absolute error was converted to a percentage using the following formula:

$AE_{adjusted}$ (%) = [AE / angle initial trial] x 100

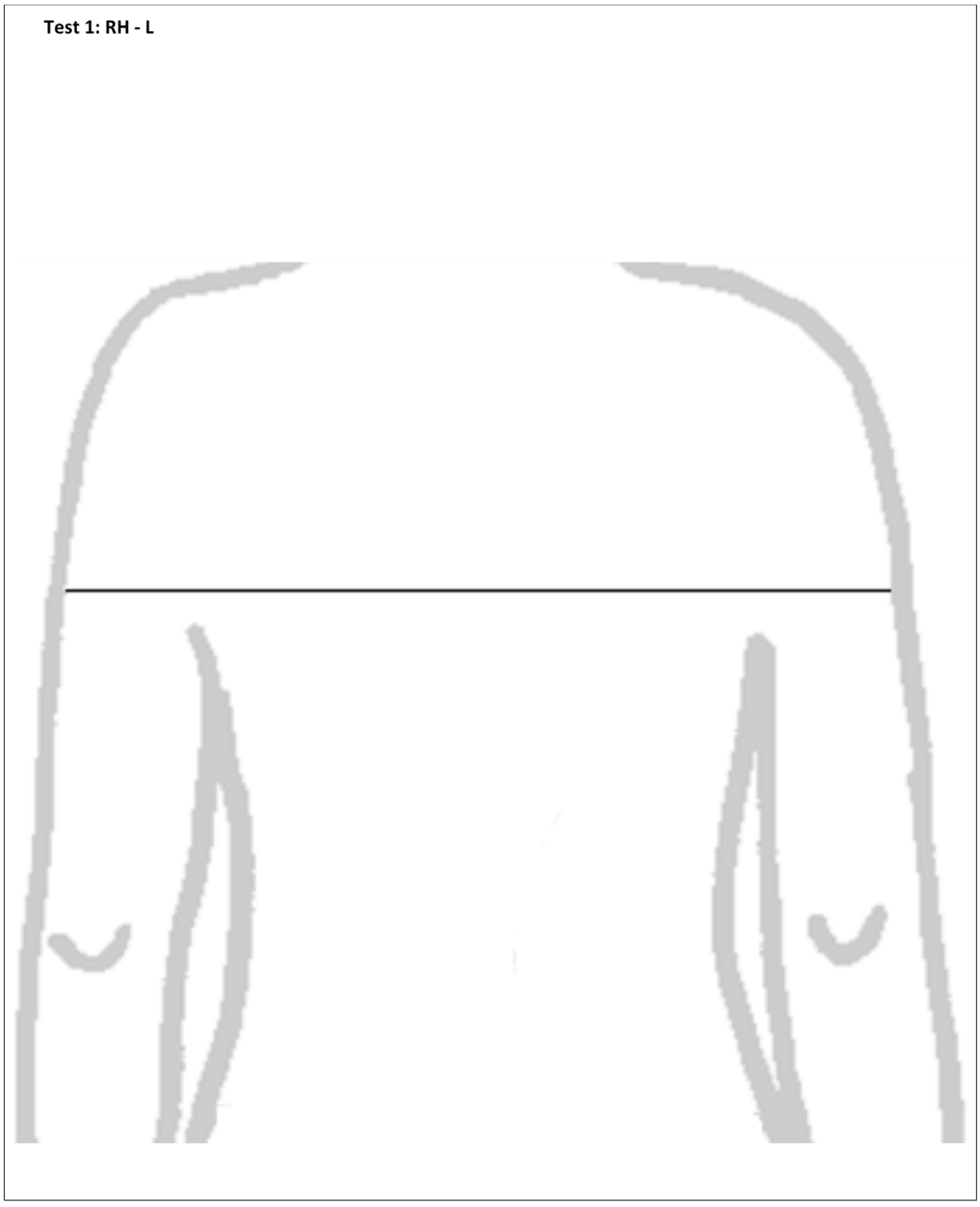
An error of 0% indicates that the participant was able to match the reference position exactly.

Appendix 18 Line bisection test (LBT)

A18.1 LBT case report form -standard (example)



A18.2 LBT case report form - body (example)



A18.3 LBT instructions

Line bisection test

Equipment:

Line bisection test papers (13 in total including example)

Pen

Table or similar wide enough for three A4 sheets in a line (landscape orientation)

Tape (optional)

Set up:

Patient sitting at table or desk.

Procedure:

Straight line

1) Show the patient the example sheet and give instructions as to what you will be asking them to do (i.e. mark the midpoint of each horizontal line). Ask them to be as accurate as possible.
2) Explain that there will be 3 horizontal lines per sheet, each of different lengths. They will complete 3 sheets with their right hand and 3 with their left hand.
3) Each sheet will be placed either directly in front of them (Centre) or left or right of centre in a randomised order. The actual position and hand to be used is described at the top of the sheet (e.g. LH-L = left hand, left side; RH-C = right hand, centre). The participant **MUST NOT** alter the position of the sheet from its assigned location. You can use a piece of tape as a guide to mark the positions.
4) Do a practice with the example sheet. Participants must mark the midpoint by drawing a single line perpendicular to the printed horizontal line. If they make a mistake, ask them to redraw where they think the midpoint is and draw a circle around their preferred option. They are only allowed to do this once.
5) For actual test, place a blank sheet in the centre position as a marker. Then, place one sheet at a time in the order they are numbered. Remove each completed sheet before giving them the next one.

Body line

1) Repeat the same procedure using the sheets with the body drawing. This time there is only one line per sheet. The order of testing (i.e. position and hand) is described at the top of each sheet.

Instructions:

"I am going to put a sheet of paper in front of you with lines on it. I want you to draw a line where you think the middle of each line is. Try to be as exact as possible"

"You will do this 3 times with your right hand and 3 times with your left. I will place the sheets in different positions. Please mark the lines with the sheet in this position - do not move it from where I put it."

A18.4 LBT scoring

Line bisection testing involved 24 separate trials involving specified combinations of hand used, line length, line type, and paper position (see appendix O1.3 for further details). These combinations were analysed for case and control participants separately according to:

- hand used (left versus right - 12 trials each),
- line length (200mm v 225mm v 250mm - 6 trials each, standard lines only),
- paper position (left v centre v right - 8 trials each),
- line type (standard v body - 18 trials and 6 trials respectively).

Data was also analysed to account for the direction of the curve within groups

For each test, the true length of the left half of the line was measured along with the perceived left half of the line as defined by where the participant placed their mark. The difference or error between these was calculated as:

Error (mm) = perceived length of left half - true length of left half

Negative distances indicate that the perceived middle of the line was to the left of the true centre point.

Error was converted to absolute error (AE) by:

Absolute error (mm) = $\sqrt{(error^2)}$

To adjust for the differences in line lengths used, the error was converted to a percentage using the following formula:

$AE_{adjusted}$ (%) = [AE (mm) / total line length (mm)] x 100

An $AE_{adjusted}$ of 0% means that the participant's estimation and the actual midline were the same. Each 1% of $AE_{adjusted}$ equates to a 1.7 - 2.5mm (depending on line length) distance between the actual midline and the participants' estimate.

Appendix 19 Dynamic balance

Dynamic balance

Equipment:

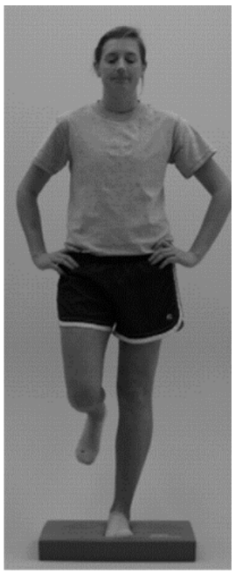
Airex foam pad

Stopwatch

Set up:

Patient standing barefoot in front of Airex foam pad which is placed on a flat non-slip surface.

Procedure:



The participants perform the test 3 times on each leg with a 15 second rest between each measurement. The participant is allowed a 15 second practice on each leg prior to taking the measurements.

Each test is timed using a stopwatch.

Instruct the participants to place their hands on their hips, close their eyes and lift their left leg so they are balancing on their right leg. Begin timing when the participant lifts their foot off the floor.

Record the length of time (minutes: seconds) that the participant can maintain their balance. The maximum time for each test is 180 seconds. If the participant can maintain this position for 180 seconds then the test is completed.

Timing is stopped upon loss of balance or opening of one or both eyes. Loss of balance includes:

- removal of one hand from the hip,
- touching the foam or floor with the non–weight-bearing foot,
- movement of the weight-bearing foot from its original position on the foam,
- movement of the foam from its original position.

Repeat on the other leg after a 15 second rest.

Each leg is tested 3 times in total.

Test legs **alternately (R - L - R - L - R - L)** with a **15 second rest** in between each leg .

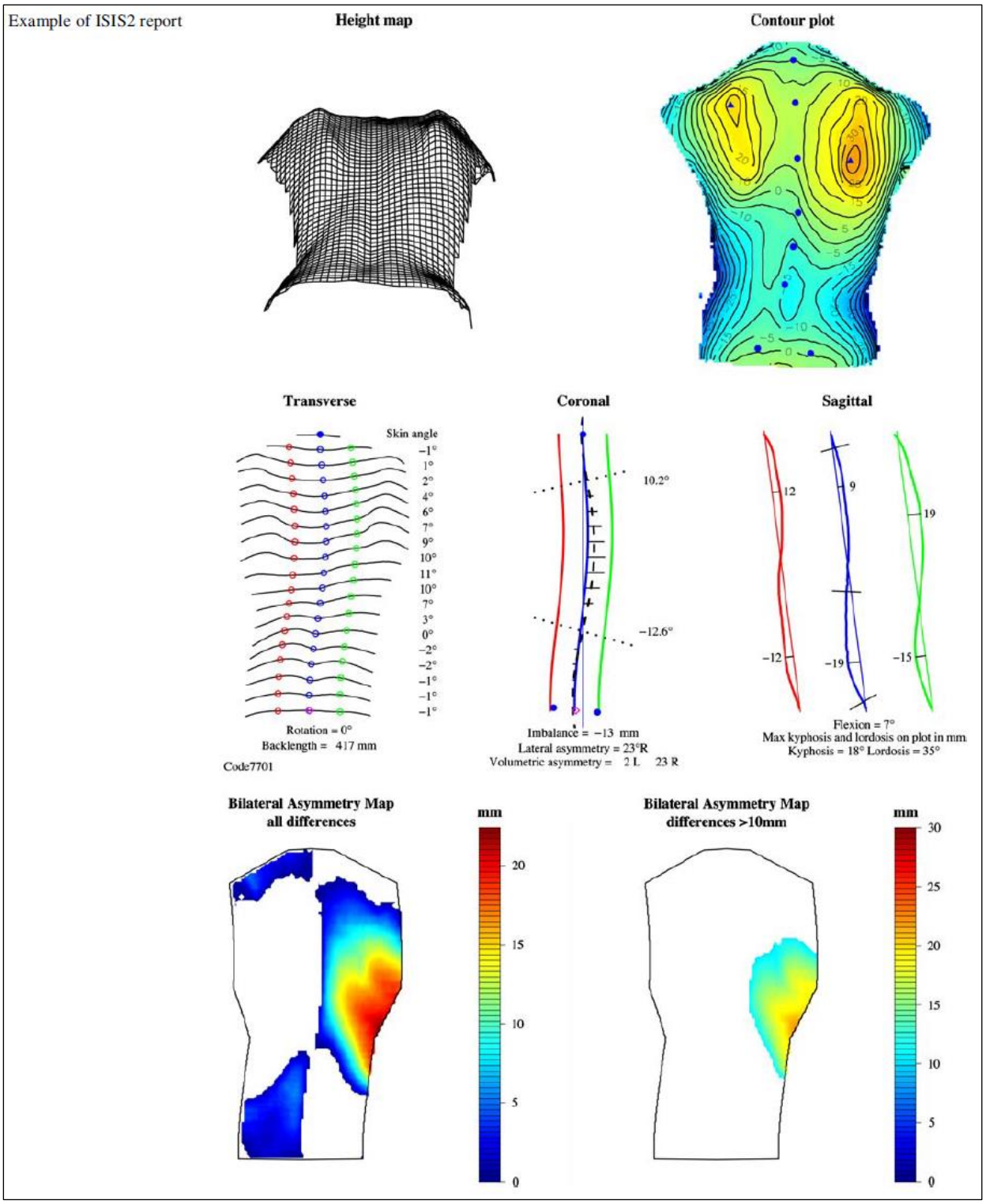
	Right leg					Left leg				
	M		S	S		M		S	S	
Trial 1		:			***15 second rest***		:			***15 second rest***
Trial 2		:			***15 second rest***		:			***15 second rest***
Trial 3		:			***15 second***		:			***Finish***

A19.1 Balance scoring

Three tests were performed on each leg. The time (seconds) for each test was recorded and the average for each side calculated as well as an overall average time.

Appendix 20 ISIS 2

The typical output following an ISIS 2 scan is shown below (from Berryman et al 1988 - see Chapter 6 for reference).



A20.1 ISIS 2 parameters

The following information is taken directly from Berryman et al 1988. Parameters used for analysis are highlighted.

A20.1.1 Height map

This shows a wire-frame plot, giving an impression of the three-dimensional shape of the back. The back is viewed from below so that any rib humps are exaggerated.

A20.1.2 Contour plot

This plot represents the shape using contour lines and colour (blue lowest to red highest). The numbers on the contours are in mm, plotted every 5 mm. The marker locations (solid blue circles) and the most prominent points on the two shoulder blade areas (solid blue triangles) are indicated.

A20.1.3 Tranverse

The shape of the transverse section at 19 equally spaced levels from the vertebra prominens to the sacrum is shown. The **rotation angle**, back length and the skin angle at each section are also shown. The open blue circles indicate the location of the spine at each level. A solid blue circle indicates the vertebra prominens; a magenta diamond indicates the sacrum. The green and red circles are on the paramedian lines at 10% of the back length to the right and left of the spine. The skin angles are measured between the paramedian points at each level, i.e. over a width of 0.2*back length. The skin angle is positive when the right side is higher.

A20.1.4 Coronal

This plot shows a fifth order polynomial curve fitted through the spinous process markers (thick blue curve) and similar curves at the paramedian locations to the right (green) and left (red). A fine blue line is dropped vertically from the vertebra prominens (gravity line). The horizontal distance between this line and the sacrum gives a measure of the **imbalance**; its value is printed at the bottom of the plot. **Imbalance** is positive when the sacrum lies to the right of the vertical through the vertebra prominens. The heavy dashed black curve is calculated from the spinous processes curve and the skin angle at each transverse location (19 levels between vertebra prominens and sacrum); it gives an estimate of the line through the

centres of the vertebrae. The angles of the perpendiculars to the points of inflection on this curve are calculated and used to compute the **lateral asymmetry** [simulated Cobb angle(s)]. The vertebra prominens and the lumbar dimples are shown as solid blue circles; the sacrum is a magenta diamond. The horizontal black lines give an indication of the difference in volume between the two sides of the back at each transverse level. These **volumetric differences** are normalised, summed and printed below the plot.

There may be one or two **lateral asymmetry** values, depending on whether a single or double curve has been found. **Lateral asymmetry** is the ISIS2 measure of coronal spinal curvature and is similar (but not identical) to radiographic Cobb angle.

A20.1.5 Sagittal

The sagittal sections through the vertebra prominens and paramedian locations to the right and left are shown. The straight line from the vertebra prominens to sacrum is presented at the **angle of flexion/extension**. This makes the stance of the patient immediately obvious to the user without needing to read the value for flexion/extension printed below the curves. The location and magnitude of the maximum kyphosis and lordosis are shown on the curves in mm. The kyphosis and lordosis angles are also presented below the curves.

A20.1.6 Bilateral asymmetry maps

These maps present the volumetric differences between the sides of the back. The left plot shows all differences between the two sides. If a part of the back is white it means that the other side is higher at that location. The differences are not normalised so that a smaller patient may well have smaller differences and yet have a worse curve. The right-hand plot shows only the differences >10 mm. Straight backs should show minimal colour in this plot and scoliotic backs should show more colour the worse the deformation is.

NB: absolute values for Coronal balance, Transverse rotation and Flexion/Extension angle were calculated and used in the analysis, retaining magnitude of imbalance but not the direction.